CFD High Lift Prediction Workshop

Trap Wing Experimental Summary, Geometry, and Repeatability

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NASA Langley Research Center

1st AIAA CFD High Lift Prediction Workshop

Chicago, Illinois

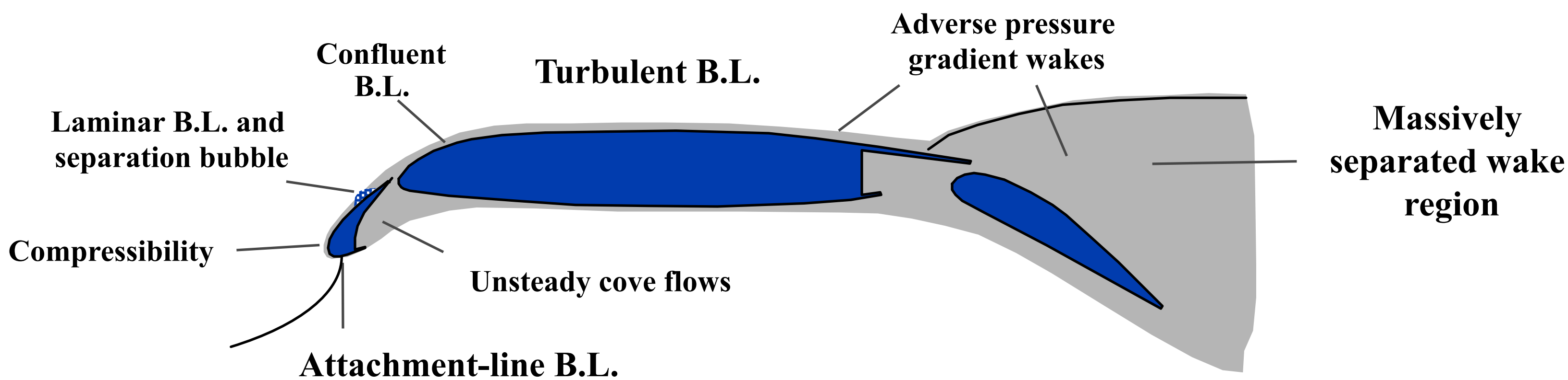
26-27 June 2010

Outline

- Summary of Trap Wing Experiments
  - Langley's 14x22 and Ames' 12 Foot: timeline and types of data
  - Plans and status of data
- Geometry
  - config 1 geometry – experiments, QAs, workshop geometry
  - config 8 geometry
  - body pod standoff
- Force and Moment Experimental Repeatability
  - config 1 and config 8
  - config 1 – more details
  - conclusions
- Summary

Motivation for Trap Wing Experiments

- Improve predictive capabilities for 3D high-lift configurations and provide insights into the flow physics
- Trap Wing model provides a "simple" geometry with the relevant flow features for high-lift flow field and presents CFD with computational challenges for:
  - massive separations
  - unsteady effects
  - strong streamline curvature
  - history effects
  - transition (wall bounded and free shear layers)



Trap Wing Model

- b/2 = 85.1”
- MAC = 39.6”
- AR = 4.56
- Λ_{le} = 33.9 deg
- $\Lambda_{c/4}$ = 30.0 deg
- taper ratio = 0.4

- original model was a horizontal tail (pre Trap Wing)

- 700 - 800 pressure orifices
- All pressure tubing runs through slat and flap brackets
- Standoff with labryinth seal
- Transition location was not fixed

Trap Wing Timeline

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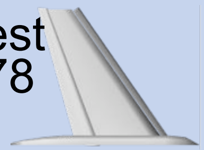
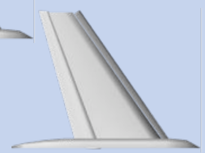
96	97	98	99	00	01	02	03	04	05	06	07	08	09	10

NASA – Ames and Langley,
Boeing – Seattle and Long Beach

Preliminary Test
14x22 Test 478
1998

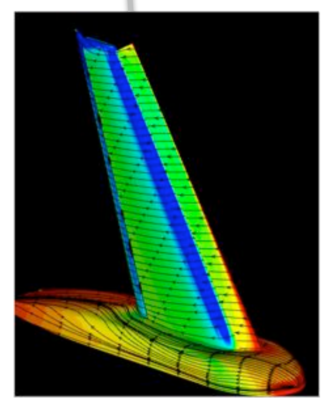


High Re Test
ARC 12’ Test 60
1999



Acoustic Test
14x22 Test 517
2003

Workshop organizing committee established - 2009



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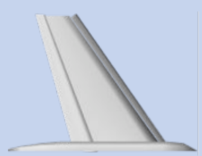
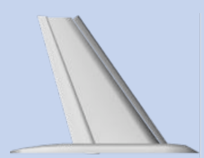
- 2001 Reno Turbulence Workshop
- 1 configuration
- more flow physics data

Tunnel Flow Survey
14x22 Test 509
2002

Transition Test
14x22 Test 506
2002



Flow-Field Test
14x22 Test 513
2003



Trap Wing Timeline

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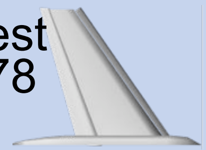

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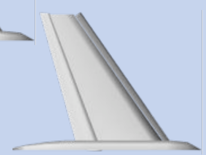

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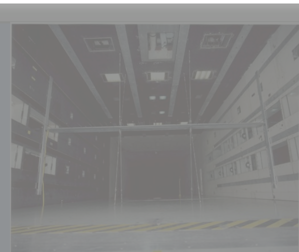

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Flow-Field Test
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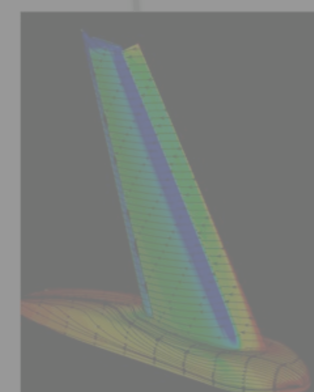

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1998 and 1999 – Types of Data

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96	97	98	99	00	01	02	03	04	05	06	07	08	09	10

	14x22	12 Foot
Re (million) Mach	4.3 0.20	3.5, 6, 9, 12, 15 0.15 – 0.25
configurations	4 full-span flap 4 part-span flap	10 full-span flap 6 part-span flap
forces/moments	✔	✔
surface pressures	✔	✔
wall pressures		✔
BL transition	limited- infrared	TSP
model velocity profiles	limited	✔
mini-tuft images		✔
acoustic	microphone array and flap edge pressure sensitive paint	

data available at: http://db-www.larc.nasa.gov/trapwing/archive/register/

workshop config 8 data is from 1998 test

1998 and 1999 12 Foot Wall Corrections

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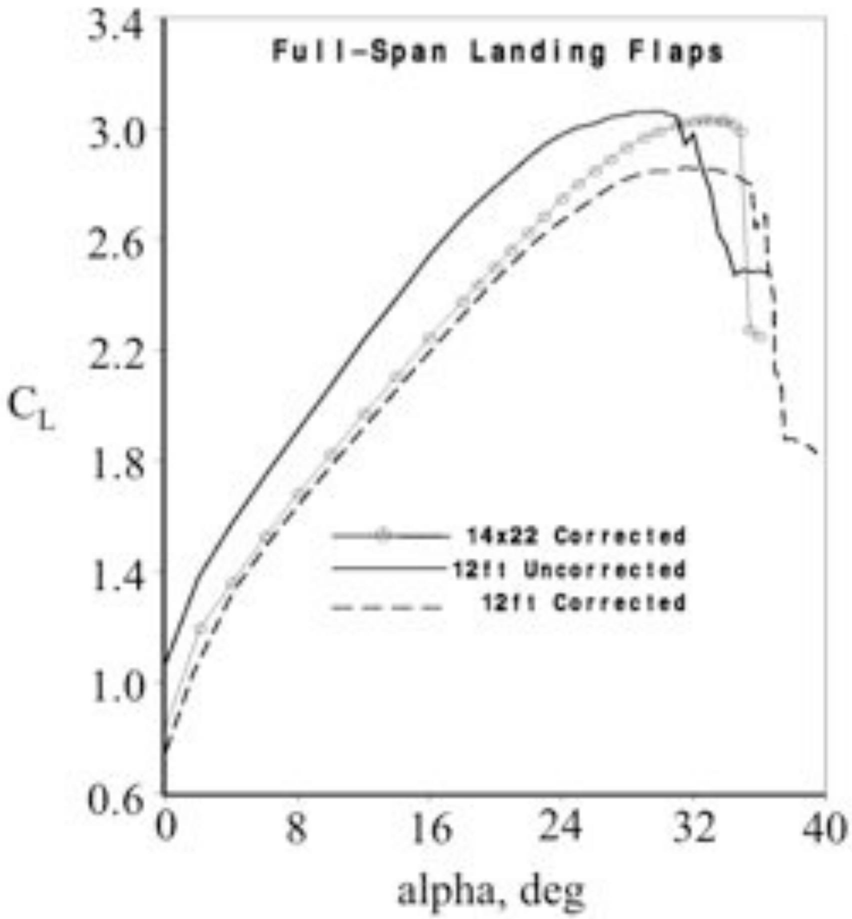
96 97 98 99 00 01 02 03 04 05 06 07 08 09 10



12 Foot data - strong recommendation to include tunnel walls in CFD modeling

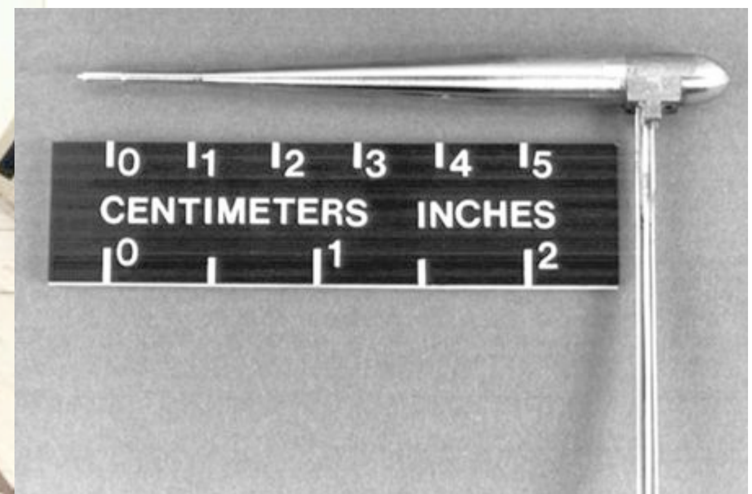
(AIAA 2000-4218, CFD Validation of High-Lift Flows with Significant Wind-Tunnel Effects, Rogers, Roth, Nash)

Figure from AIAA-2000-4217 by Johnson, Jones, Madson

1998 and 1999 Model Traverse With 7-Hole Probe

Velocity component data not yet available because of questions about probe head positioning relative to the flap.

These questions are being sorted out now and then data will be reduced.



Trap Wing Timeline

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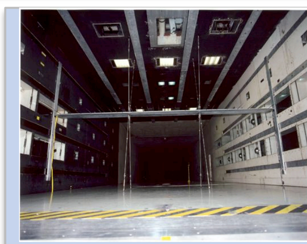

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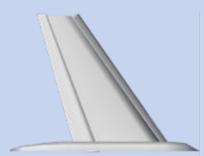

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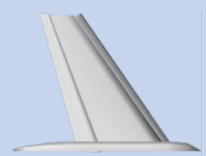

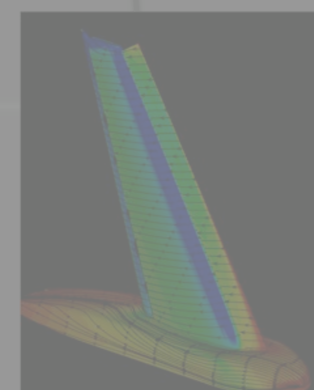

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High-Lift Flow Physics Experiment

- **Purpose -** To obtain detailed flow-field information on a three-element, high-lift wing configuration for the validation and assessment of CFD predictions used in high-lift flow solvers.

- **Approach**
  - Part 1: Measure tunnel boundary conditions
  - Part 2: Measure boundary layer transition, separation, and reattachment regions - hot-film anemometry
  - Part 3. Measure instantaneous velocity field – 3D PIV

- **Trap Wing Configuration**
  - config 1 (baseline full-span flap landing configuration)
    - slat: deflection 30°, g/c = 0.015, h/c = 0.015
    - flap: deflection 25°, g/c = 0.015, o/c = 0.0026 (original config 1 o/c=0.005)

2002 Tunnel Flow Survey

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96 97 98 99 00 01 02 03 04 05 06 07 08 09 10

- Pitot-static probes (14)
- 7-Hole Probes (7)
- Total Temp. Probes (3)
- Hot Wires (2)

2002 Tunnel Flow Survey – Types of Data

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96 97 98 99 00 01 02 03 04 05 06 07 08 09 10

	14x22
dynamic pressure (psf)	5 - 135
spatial distributions of • flow angle • temperature • total and static pressure • turbulence intensity	✔
tunnel walls BL profiles (4)	✔
wall pressures – 3 walls	✔

16” BL rake

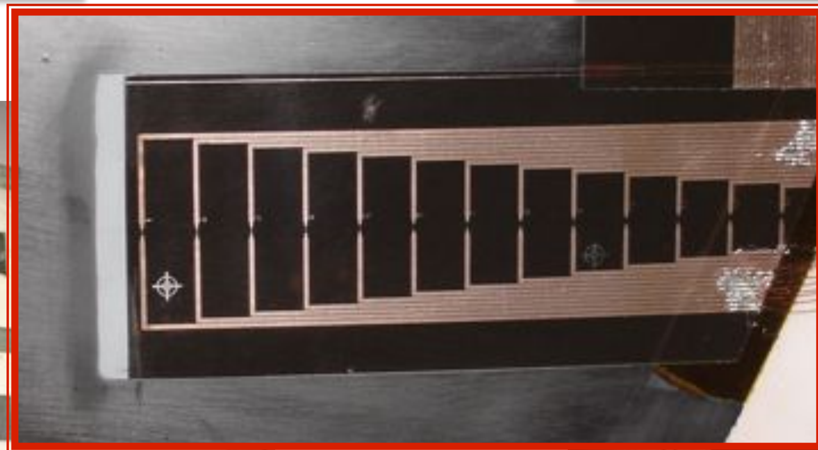
Tunnel turbulence intensities are documented in NASA TP-2004-213247 by Neuhart and McGinley.

Rest of the data has been reduced, but not published.

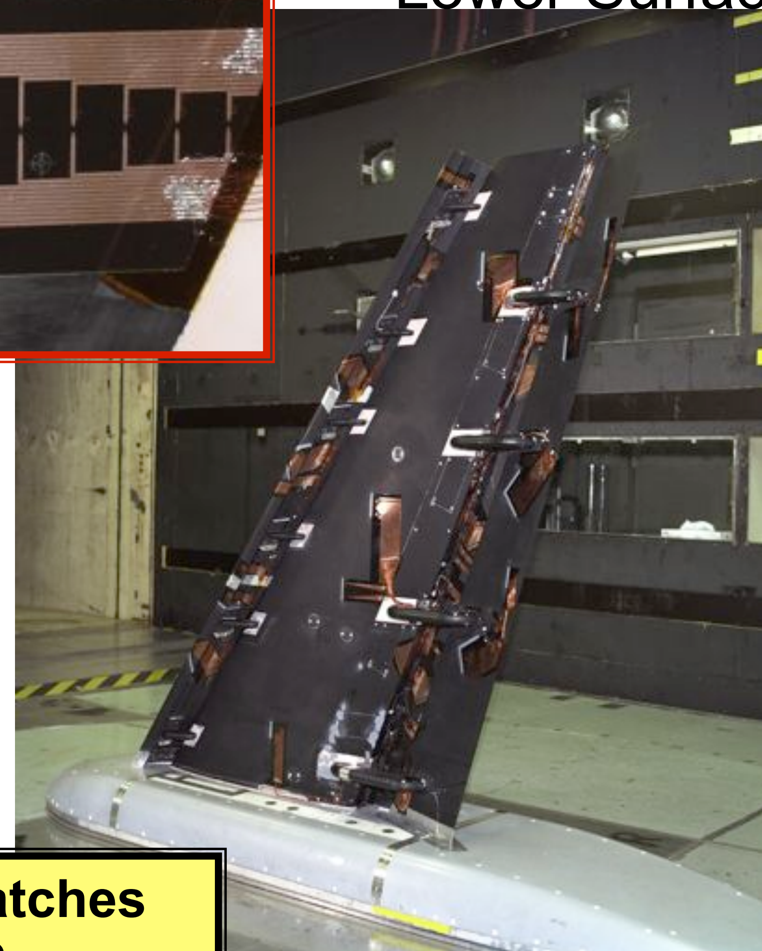
2002 Transition Test

96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10

Upper Surface



Lower Surface



40 Hot-Film Patches
528 Individual Sensors
24 Anemometers

2002 Transition Test – Types of Data

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96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10

	14x22
Re	4.3 million
configuration	1 full-span flap landing (config 1)
forces/moments	✔
surface pressures	✔
wall pressures (3)	✔
tunnel walls BL (4)	✔
model deformation and wing twist	✔
transition	hot films

Hot film measurements taken at 15 different alphas between -4 and 37 degrees

BL state and attachment lines at alpha = 8.8, 12.9, 17.1, and 25.3 degrees are documented in AIAA-2005-5148 paper by McGinley, Jenkins, Watson, Bertelrud

2003 Flow Field Test

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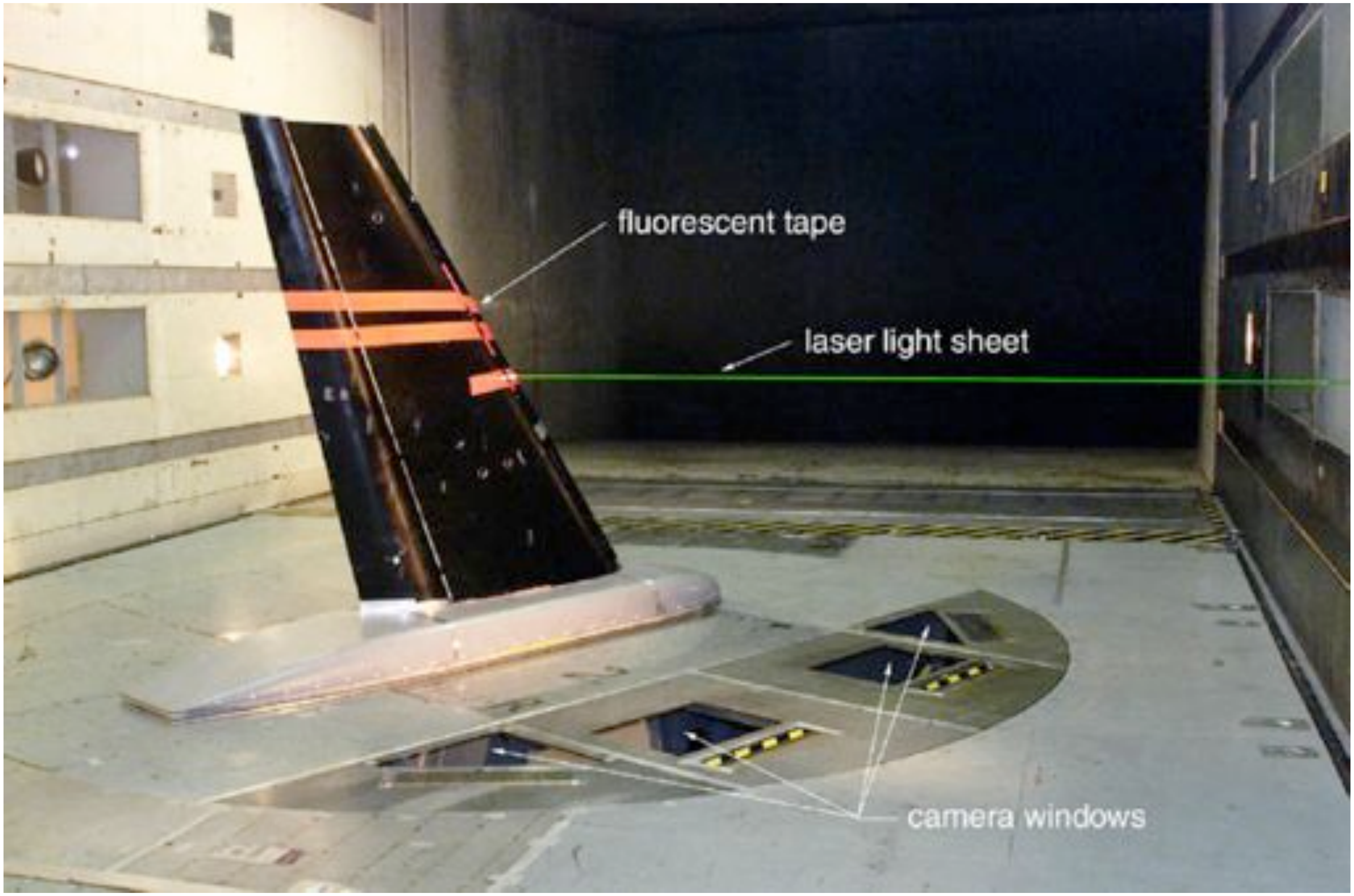

2003 Flow Field Test – Types of Data

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	14x22
Re	4.3 million
configuration	1 full-span flap landing (config 1)
forces/moments	✔
surface pressures	✔
wall pressures (3)	✔
velocity fields	PIV

- First use of PIV in the 14x22 – 6”x8”
- Now – large field of view – up to 3’ x 6’

- Trap Wing PIV data has not been reduced using new software that has the flexibility to handle the camera orientations. If these issues can be worked through the data can be reduced.
- PIV lessons learned documented in NASA TM-2003-212434 by Watson, Jenkins, Yao, McGinley, Paschal, Neuhart.

Status and Plans For Experimental Data

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1998 & 1999	• f/m, surface pressures, 12 Ft wall pressures on existing website • 14x22 and 12 Ft model velocity profiles to be worked • 12 Ft mini-tuft images and transitional info to be gathered and packaged
2002 Flow Survey	• turbulence intensities have been published • rest of data had been through a preliminary reduction – to be gathered, finalized, packaged
2002 & 2003	• hot film data has been analyzed and published for 4 angles • rest of hot film data - ? • PIV data – needs work - ? • f/m, pressures, model deformation, etc to be packaged

- All experimental data needs to be gathered in one place and made useful.
- Some corrections are needed to existing website and fill in missing data.
- The workshop has provided the opportunity to package this data set.

Model Differences Between Experiment and CFD

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Experiments	CFD
tunnel walls with corrections to free air	free-air
laminar/transitional/turbulent flow	fully turbulent
brackets	no slat or flap brackets (except optional case 3)

Config 1 model geometry settings are the same between experiment and CFD except for flap overlap (o/c) settings

Geometry – flap and slat settings

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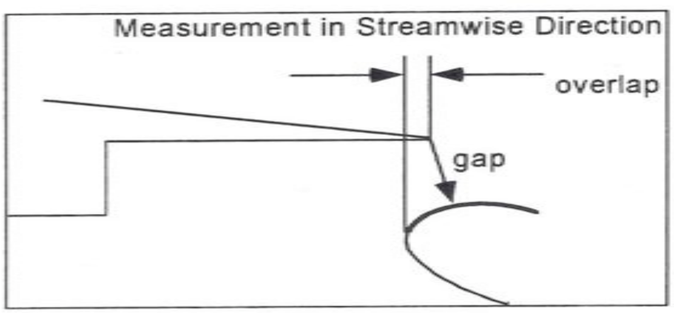
	config 1	config 8
slat deflection	30	30
slat gap (g/c)	0.015	0.015
slat height (h/c)	0.015	0.015
flap deflection	25	20
flap gap (g/c)	0.015	0.015
flap overlap (o/c)	target: 0.005 see next slide	0.005

Trailing Edge Setup Definitions



Geometry – config 1 flap overlap

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- 1998/1999 tests: no issues noted with setting o/c=0.005
- 2001/2002 model work done for hot film test – shims modified
- setup for 2002 test
  - unable to set flap g/c and o/c as 1998
  - decision to set g/c same and accept the o/c (0.0026)
  - both g/c and o/c consistent along span
- 2002 QA primarily for hot film locations on assembled model
  - Langley CFD folks discovered:
    flap overlap varies along span and flap gap was consistent
- 2004 – pulled model out of storage and re-assembled and set flap; settings same as in 2002; tried to make it match QA results – not physically possible
- 2004 QAed again
  - QA results - flap overlap consistent; gap varies along span

Geometry – for workshop

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- choices for workshop: config 1
  1. as–designed files from Trap Wing Archive website (1998/1999 tests)
  2. 2002 QA of assembled model
  3. 2004 QA of assembled model
- committee decision: 2002 QA results
  - measured with deployed elements
  - accept the issue of overlap
    - CFD code-to-code comparisons using same geometry
    - experiment is a reference for all the CFD
- config 8 workshop geometry
  - from workshop config 1 geometry; config 1 flap transformed to stowed position and then transformed to config 8 as-designed settings

Geometry – 0.95” standoff

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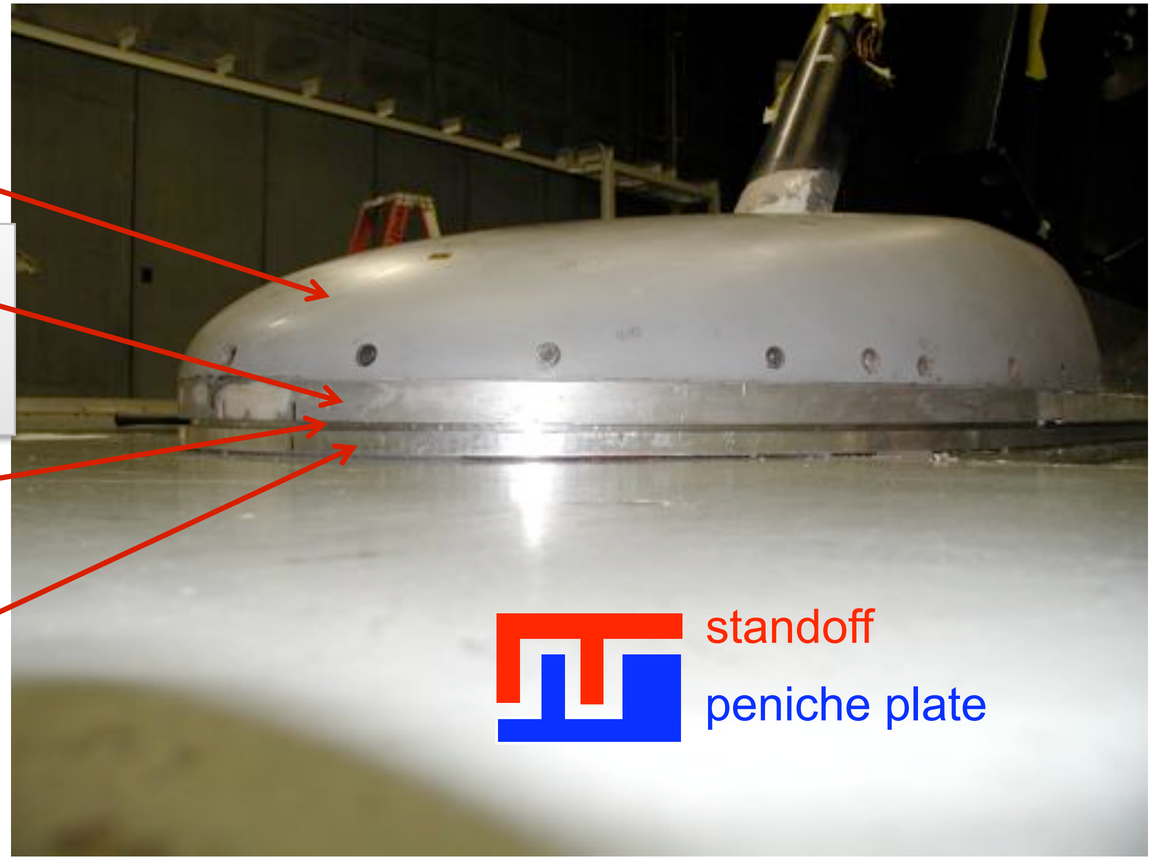
Looking at nose of model mounted to floor in 14x22

body pod

0.95” standoff
- loads measured by balance

gap

peniche plate
- not measured by balance



- Standoff, gap, peniche plate make up a labyrinth seal
- Original model sealed differently – didn’t have standoff

Geometry – 0.95” standoff

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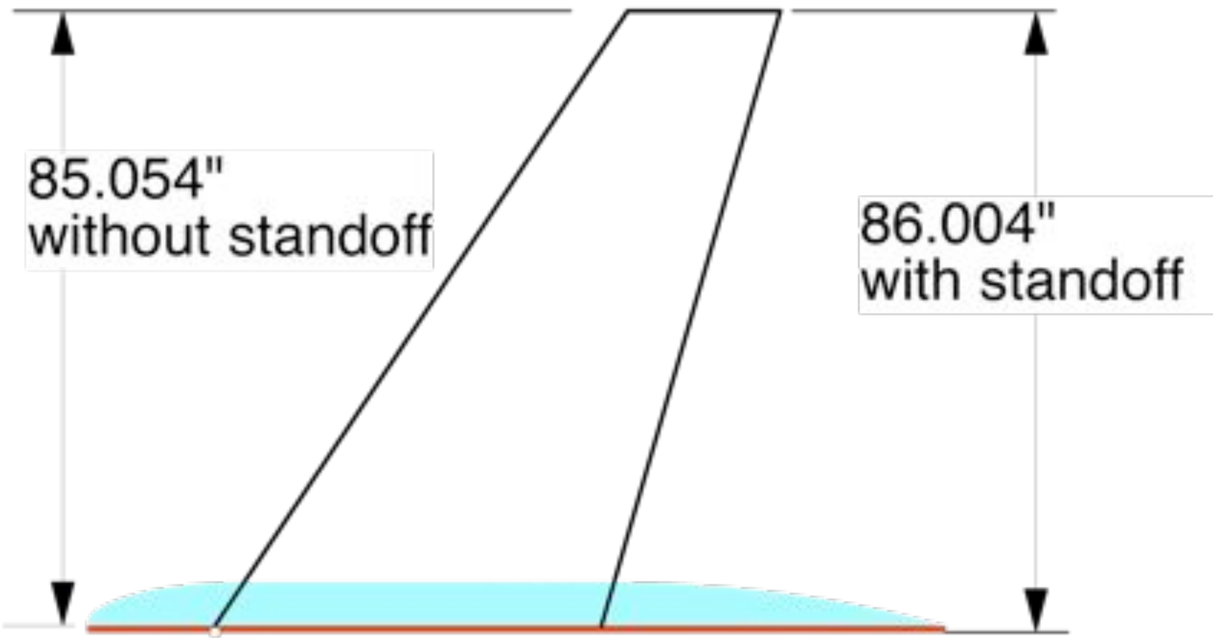

original model was without this standoff, reference point was bottom of body pod – Trap Wing also used the bottom of body pod as reference point

- but standoff loads are measured by the balance, so CFD workshop geometry symmetry plane is at the bottom of the standoff

Force and Moment Repeatability

- method
- config 1 and config 8 plots – curve fits, bounds, experimental data from workshop website
  - CL vs alpha
  - Cm vs alpha
  - CD vs alpha
  - CL vs CD
  - CL vs Cm
- config 1 plots – all 14x22 experimental data over the years
  - CL vs alpha, residuals
  - Cm vs alpha, residuals
  - CD vs alpha, residuals
  - CD vs CL
- repeatability conclusions

Repeatability Method

Using methodology described by Wahls, Adcock, Witkowski, Wright (NASA TP 3522)

- least squares polynomial curve fit based on all the data in a given alpha range for a given configuration
  - alpha range and order of curve fit are subjective, chosen by looking at residuals and trying to minimize the error over the range
- assessing repeatability by amount of scatter about this curve fit
  - prediction intervals – bounds about the curve fit related to the probability that any single future observation will be within this interval (95%)
  - confidence intervals – bounds about curve fit that encompasses the true value within a certain probability (not shown)

Because of biases in the data this violates statistical principle of "randomness" but is still a useful measure of the data scatter.

CL vs alpha – config 1 and 8

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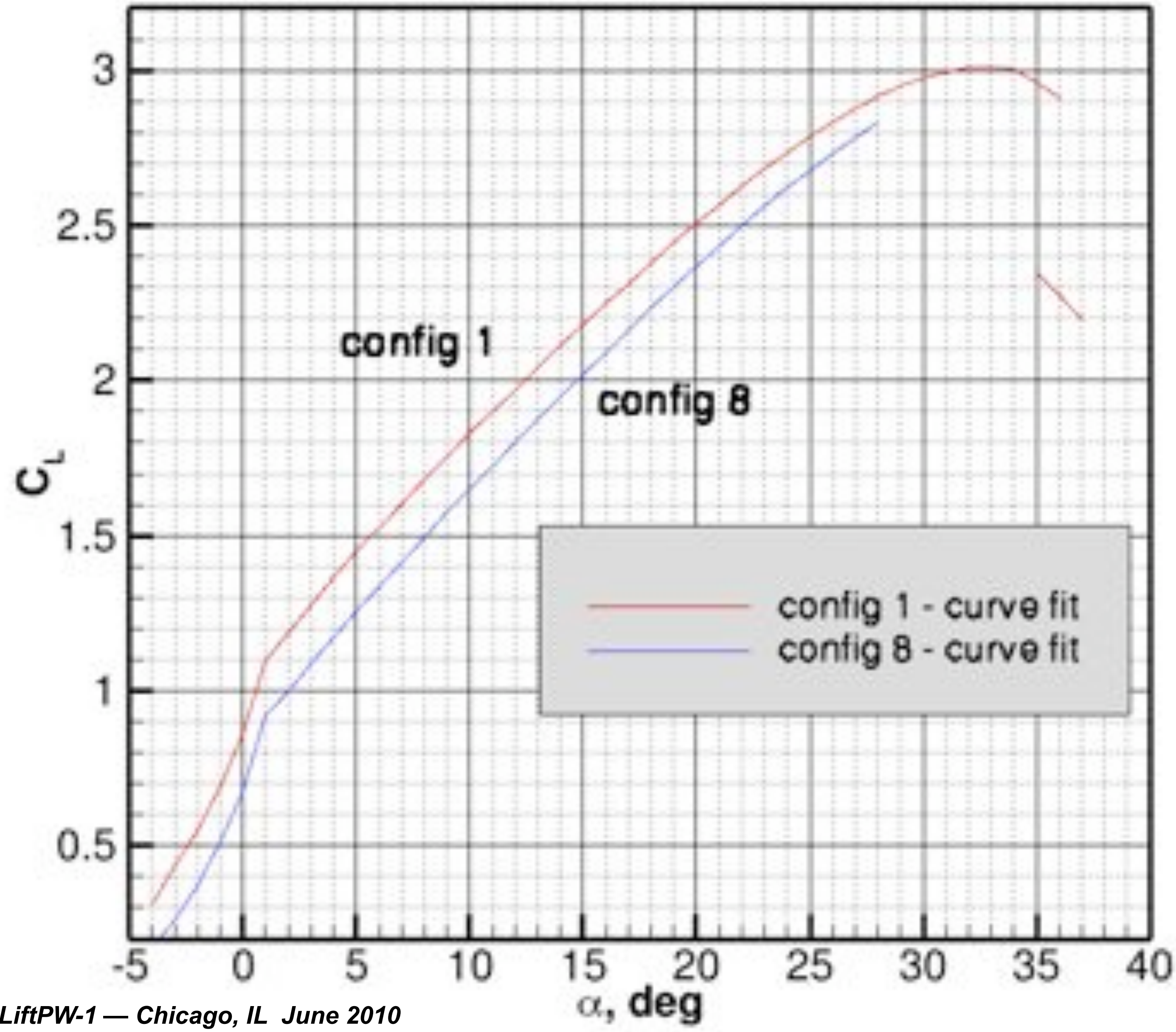

CL vs alpha – config 1 and 8

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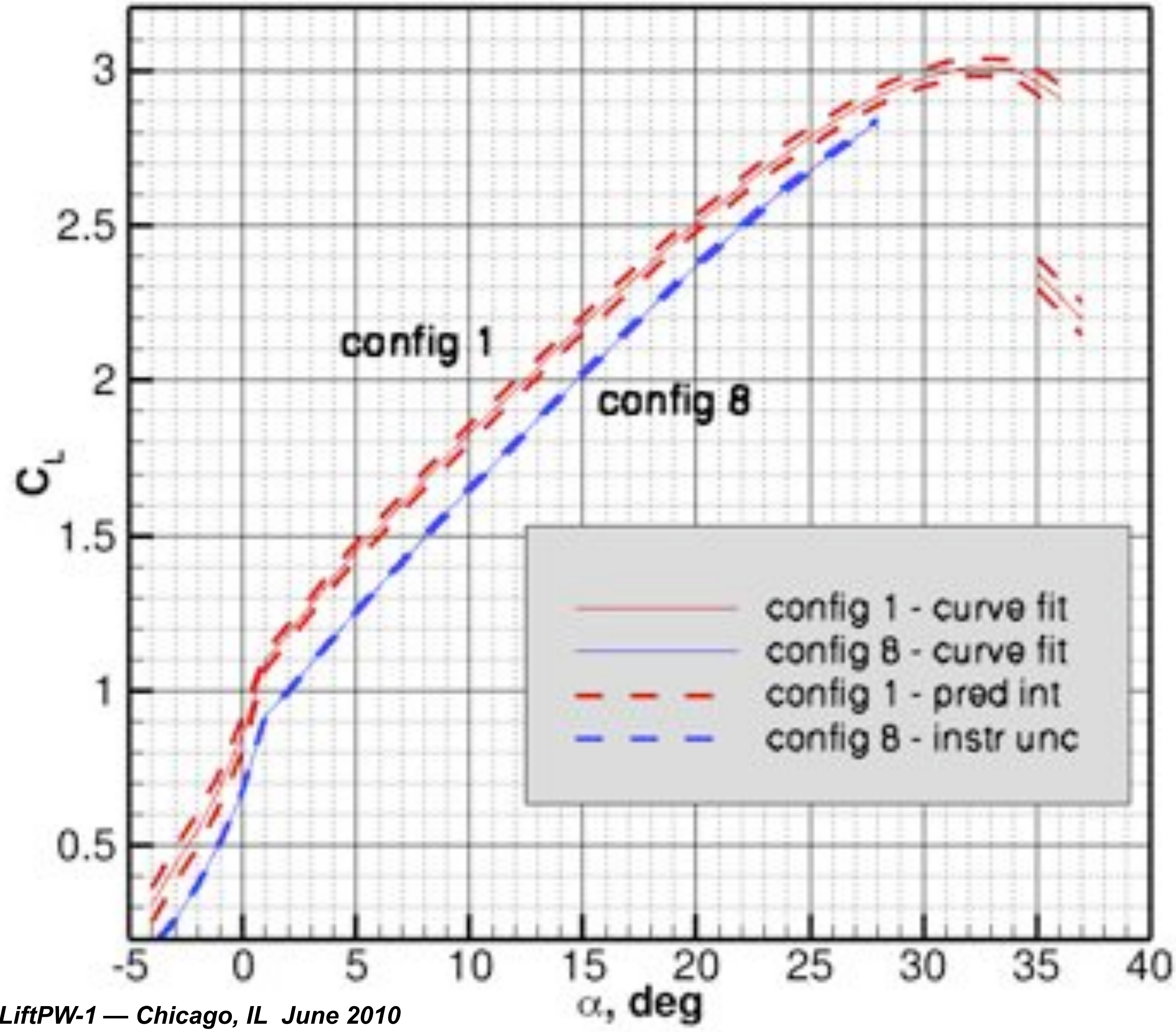

CL vs alpha – config 1 and 8

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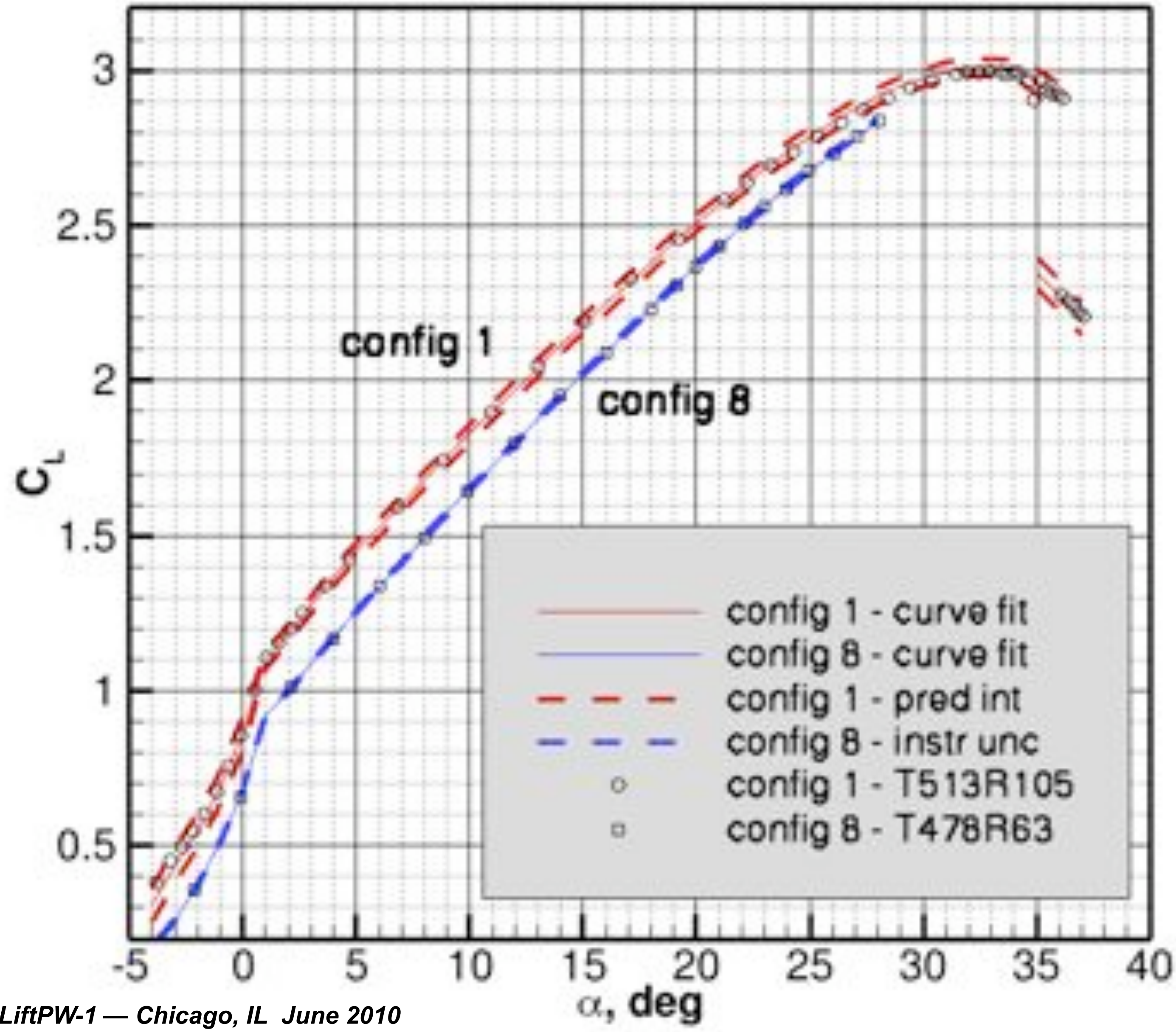

Cm vs alpha – config 1 and 8

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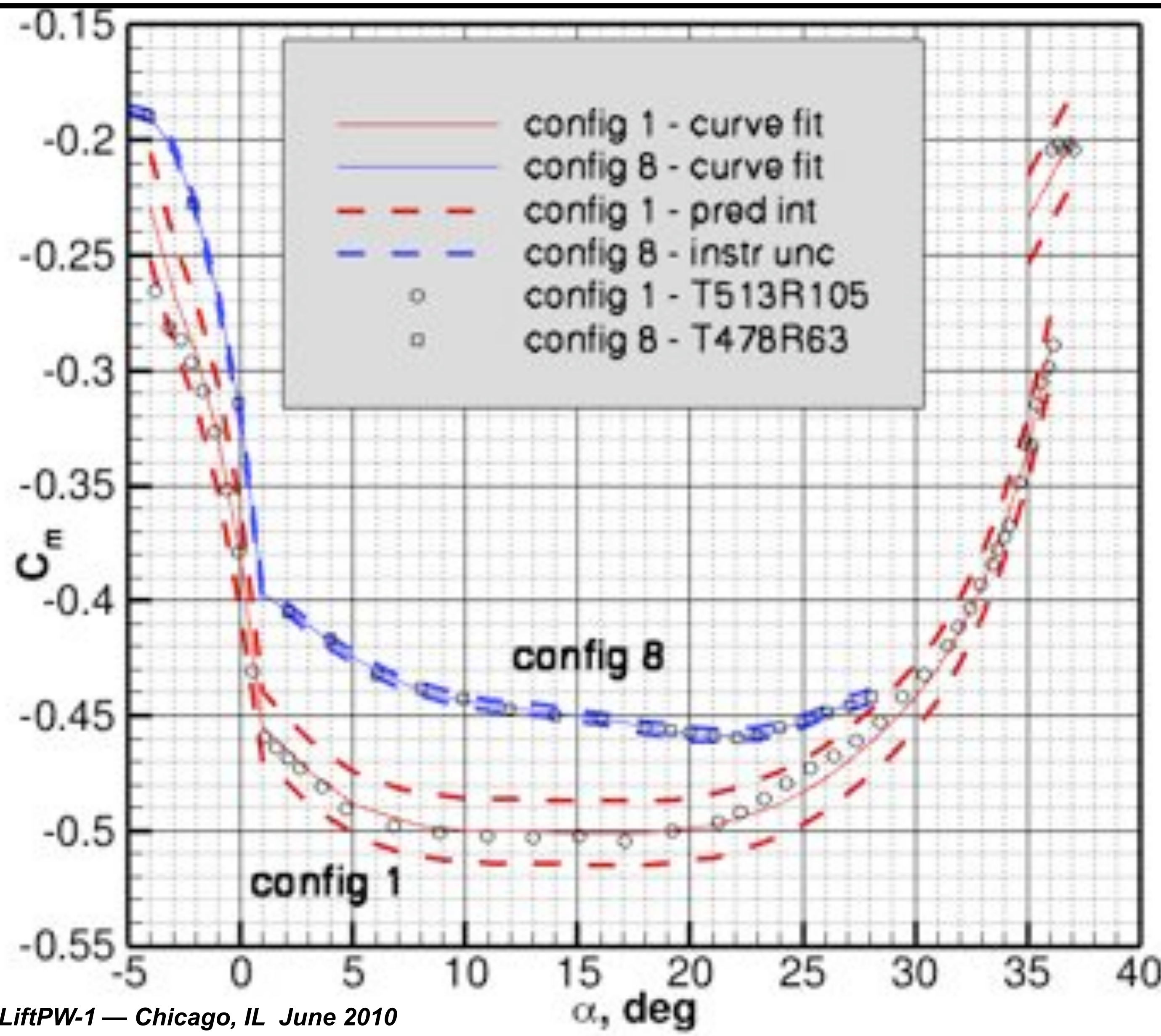

CD vs alpha – config 1 and 8

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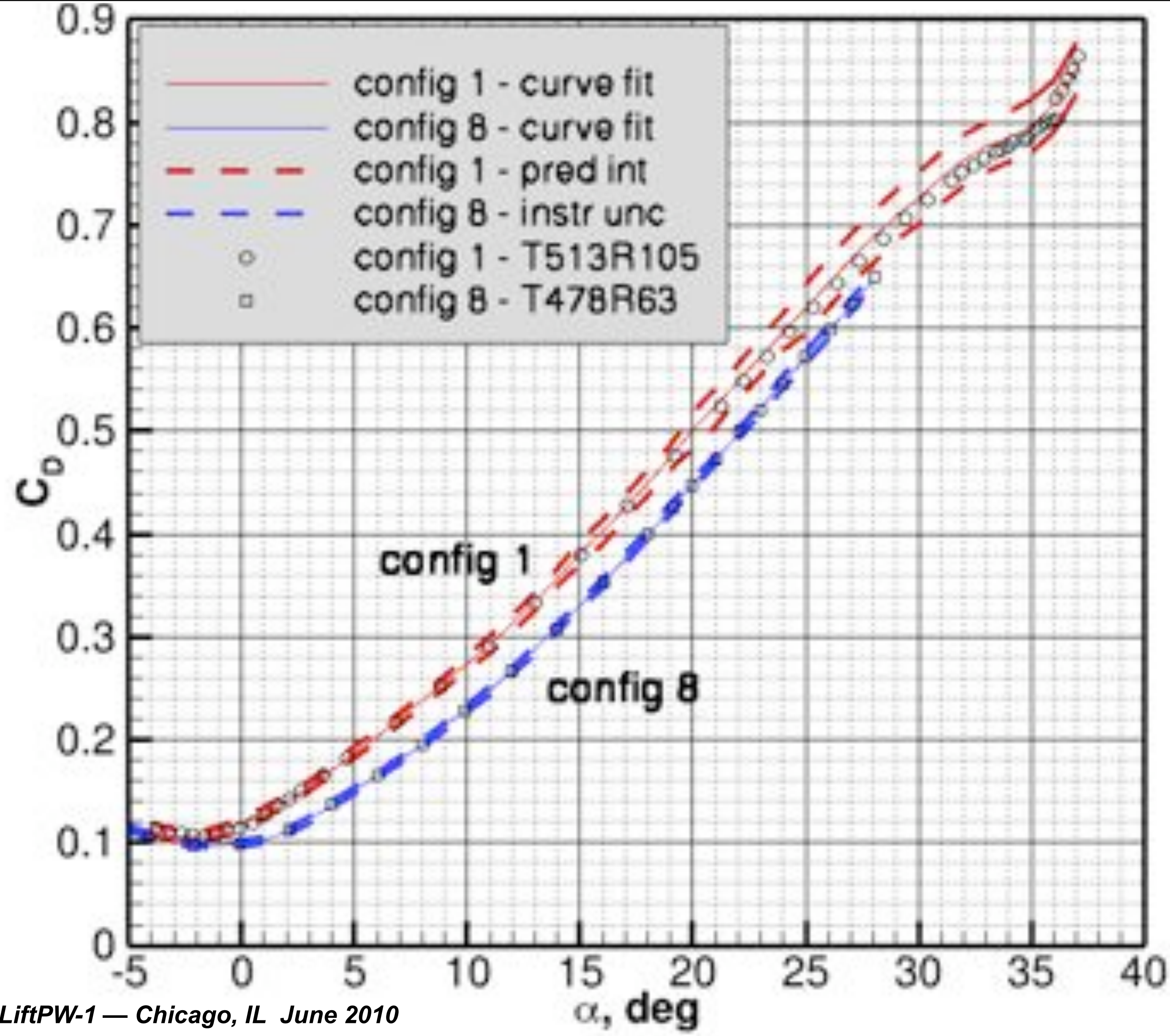
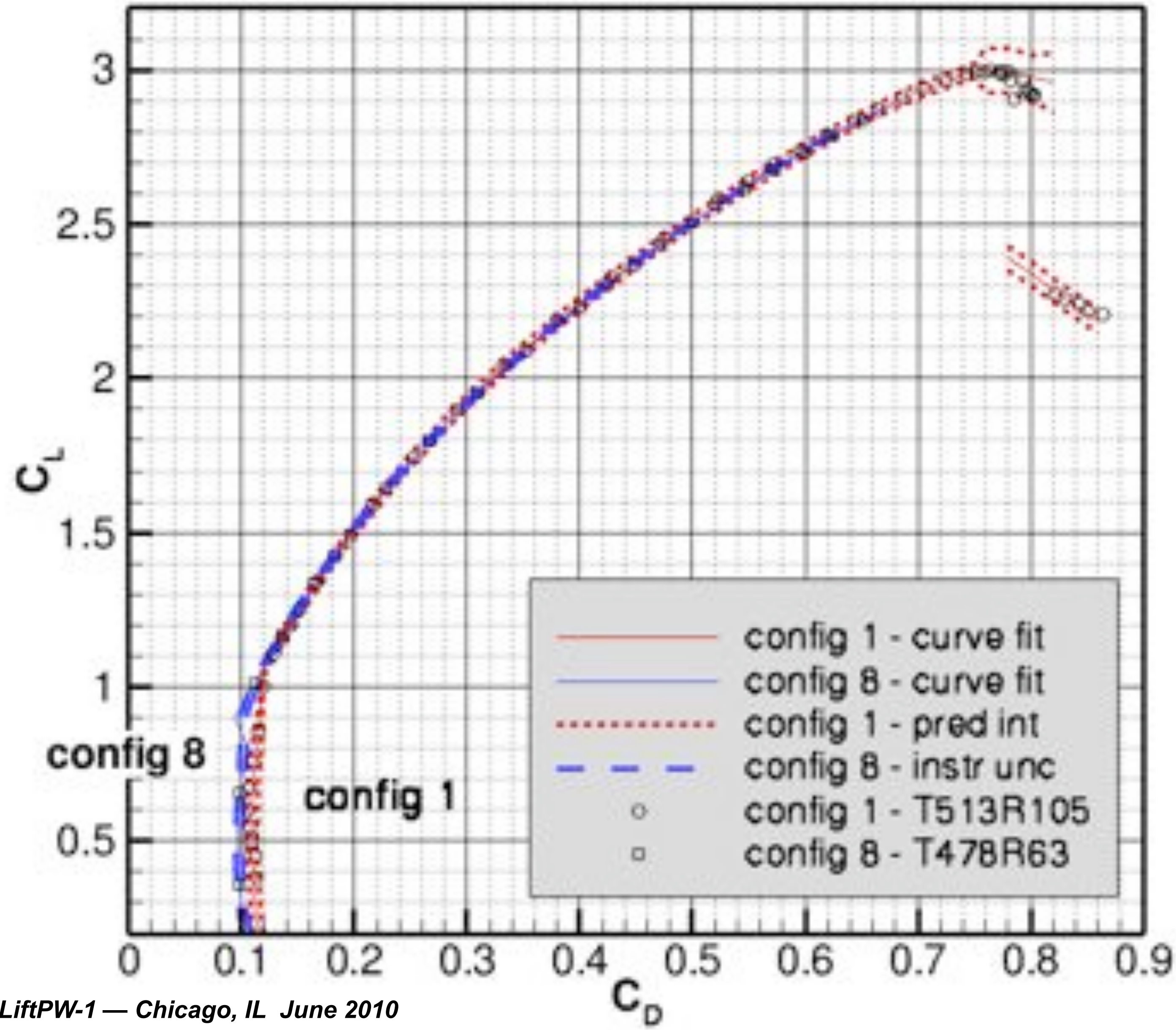
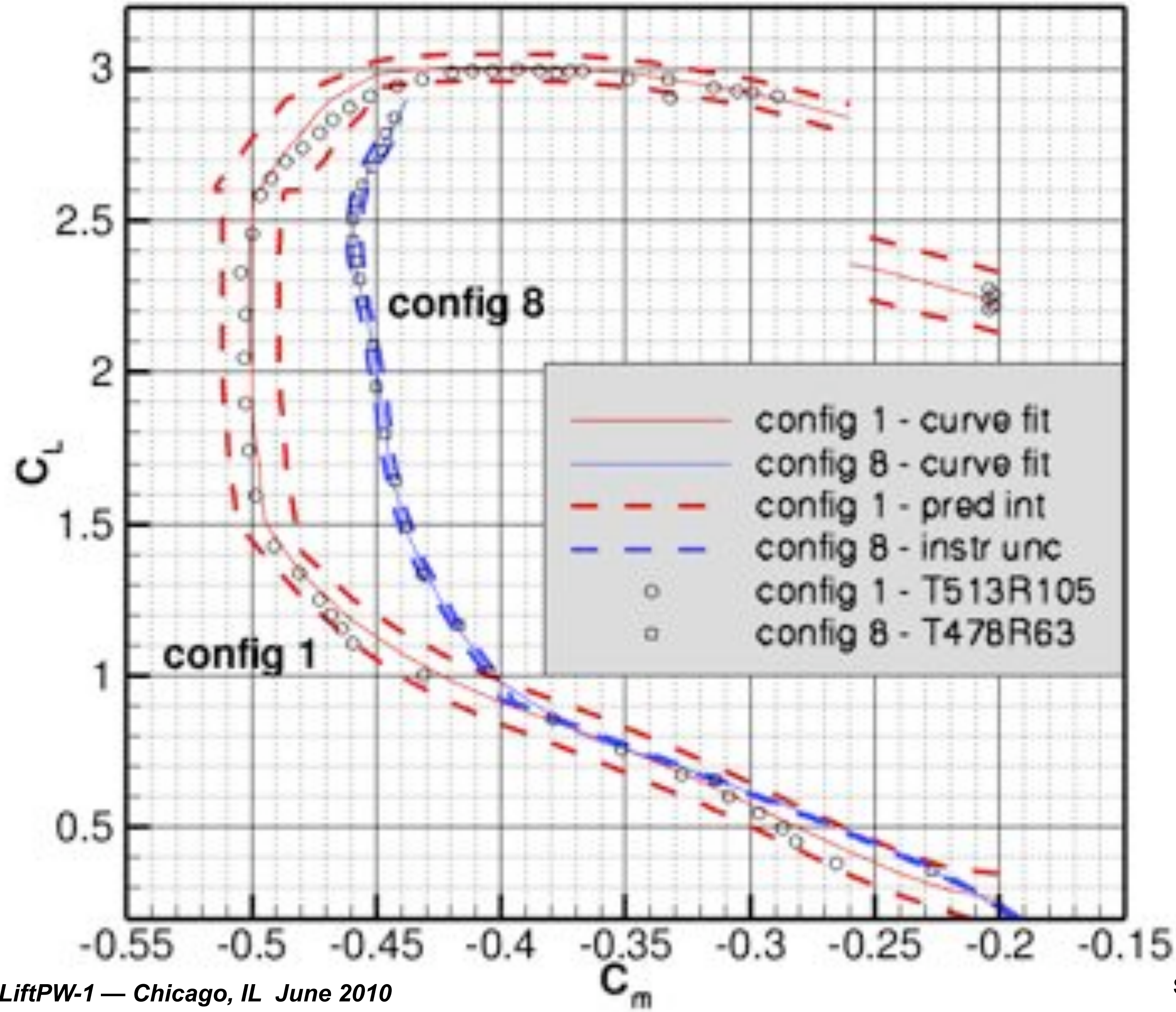


CL vs CD – config 1 and 8



CL vs Cm – config 1 and 8



CL vs alpha – config 1

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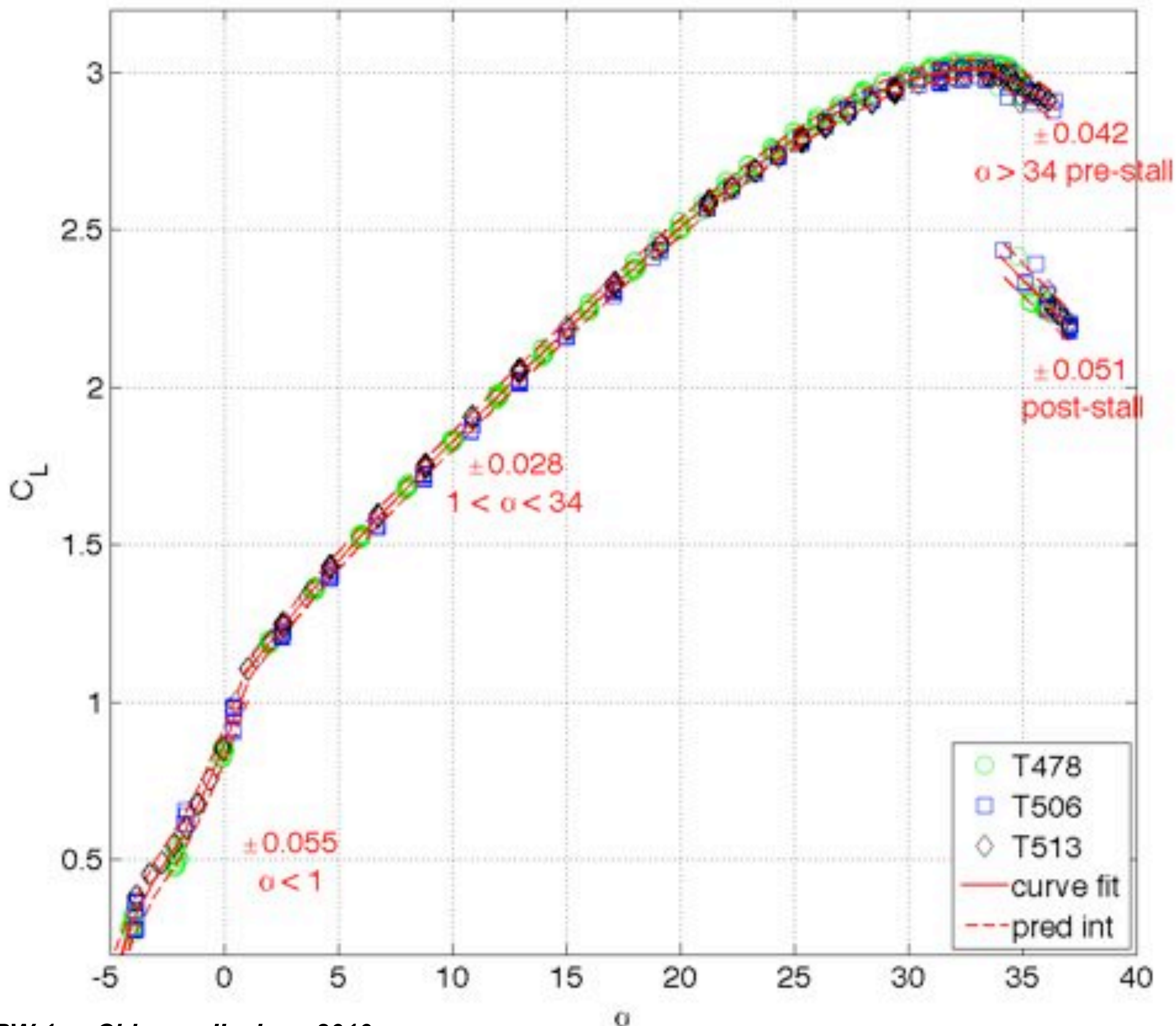

CL vs alpha – config 1 residuals

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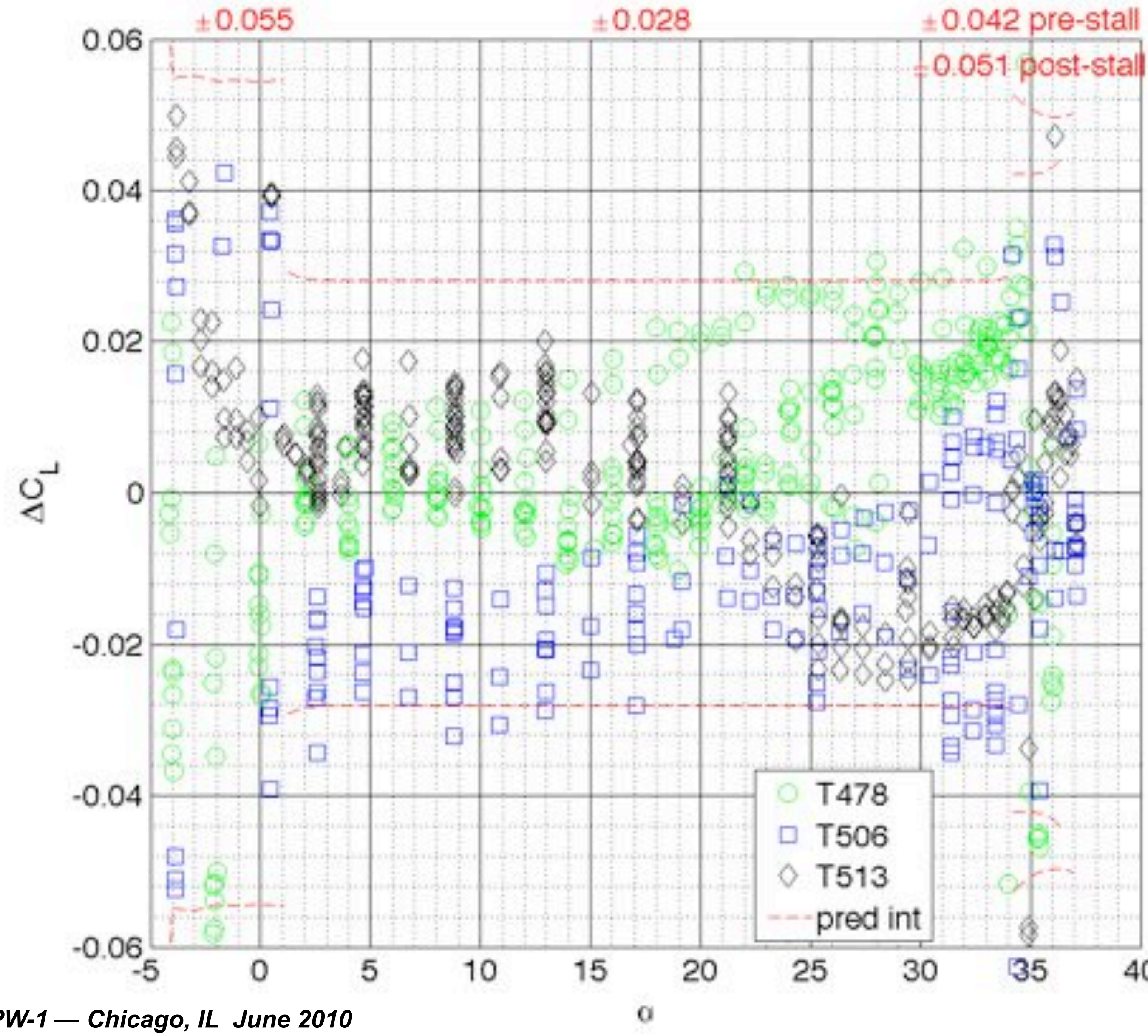

Cm vs alpha – config 1

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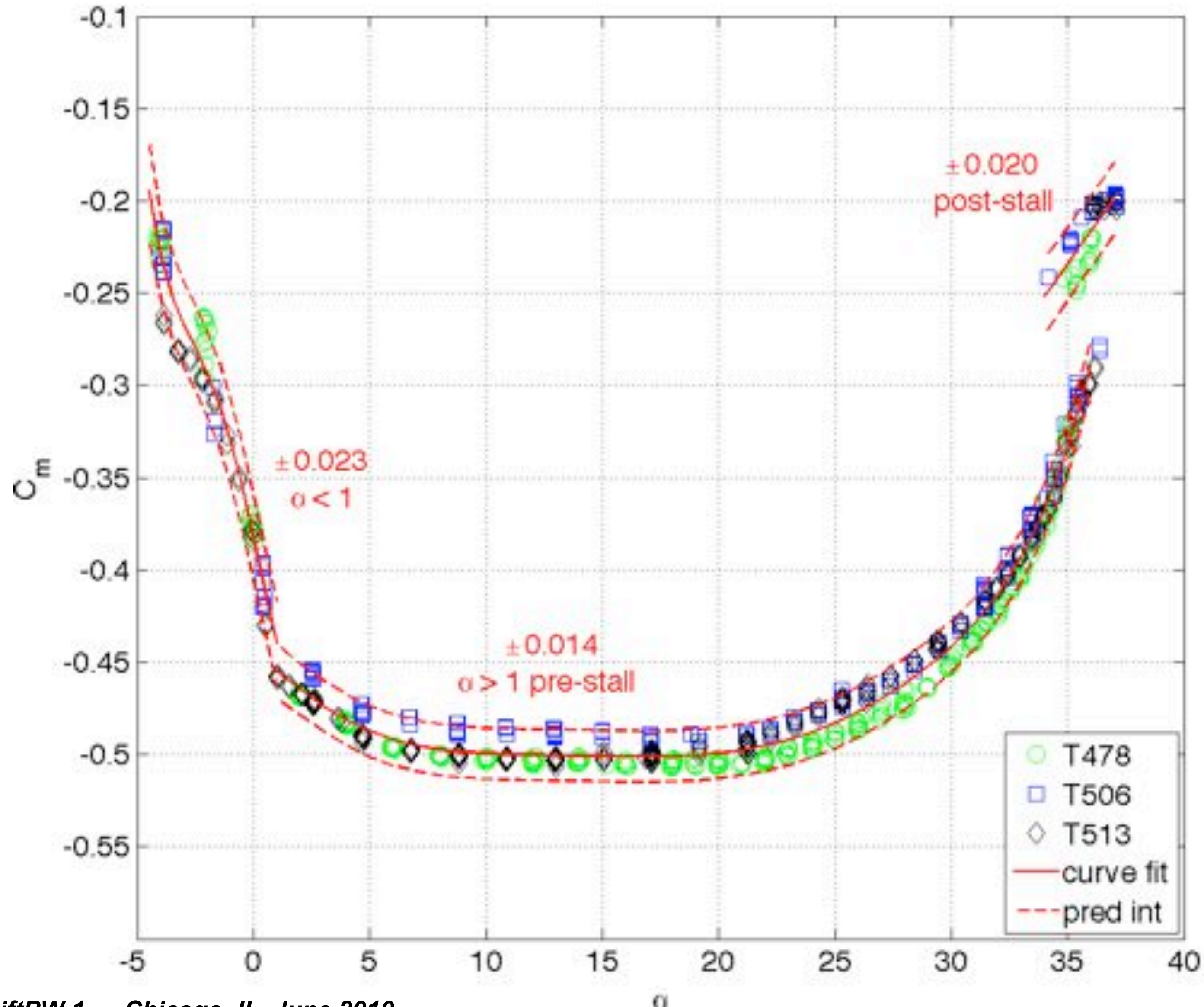

Cm vs alpha – config 1 residuals

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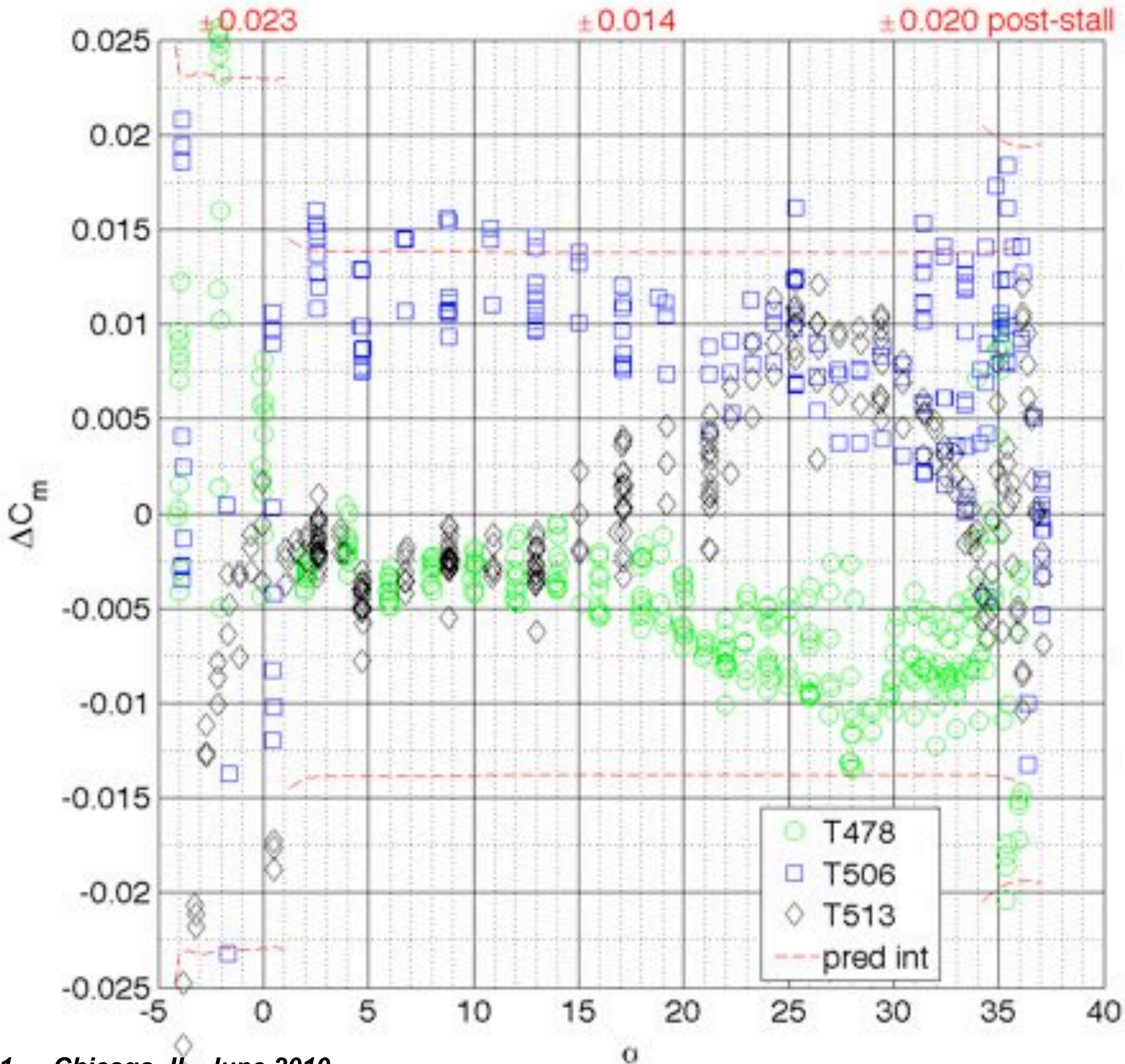

CD vs alpha – config 1

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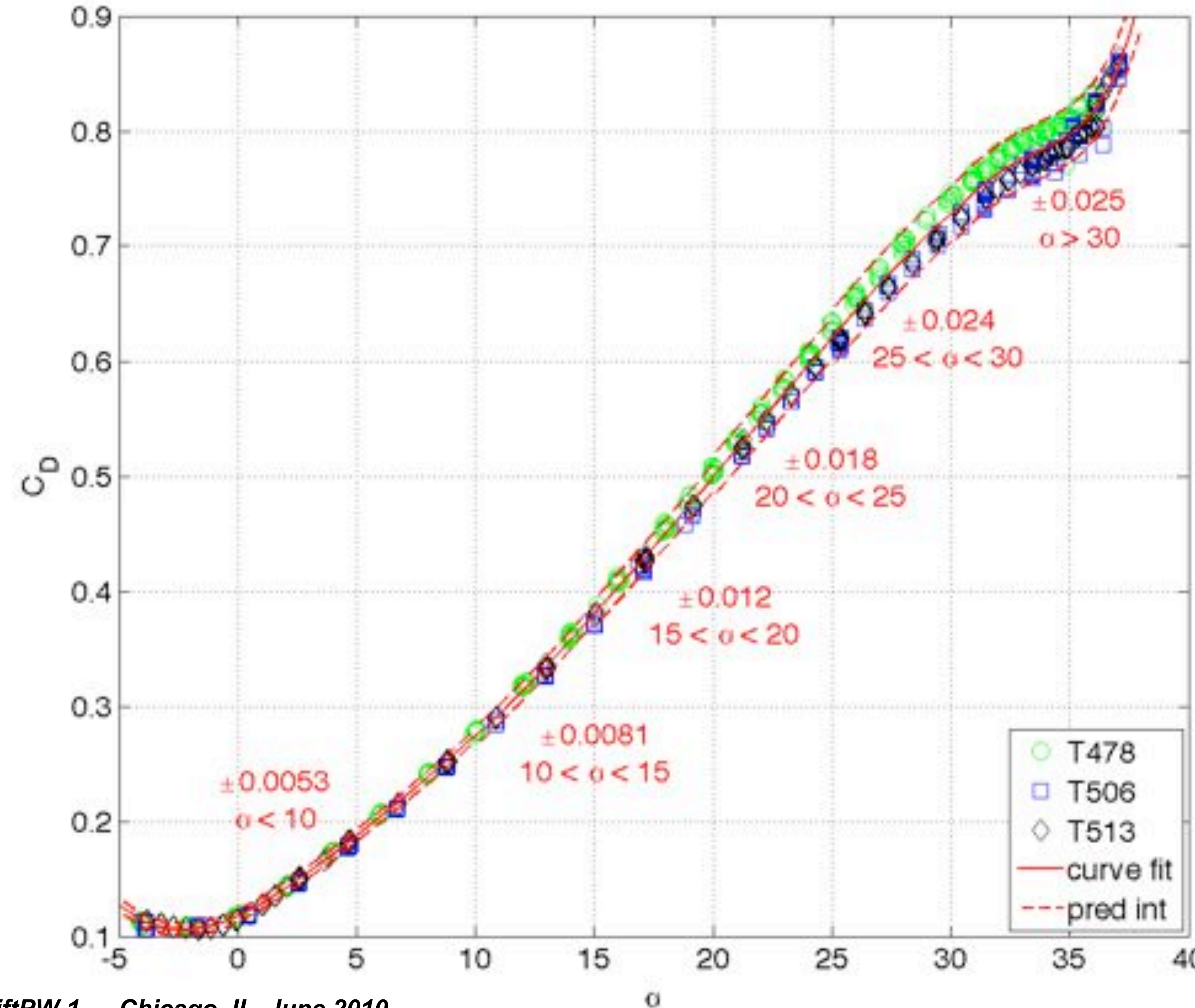

CD vs alpha – config 1 residuals

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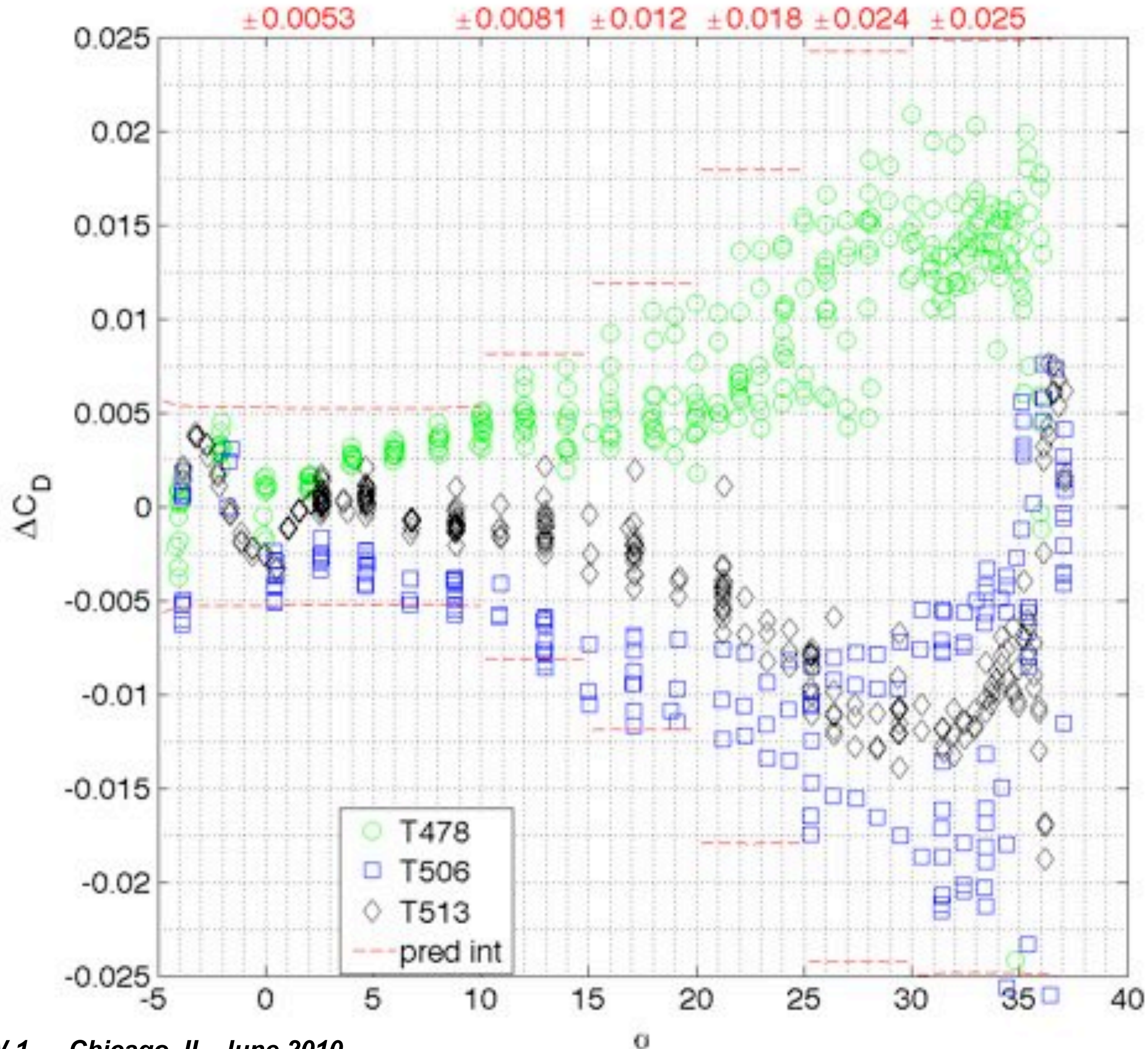

CD vs CL – config 1

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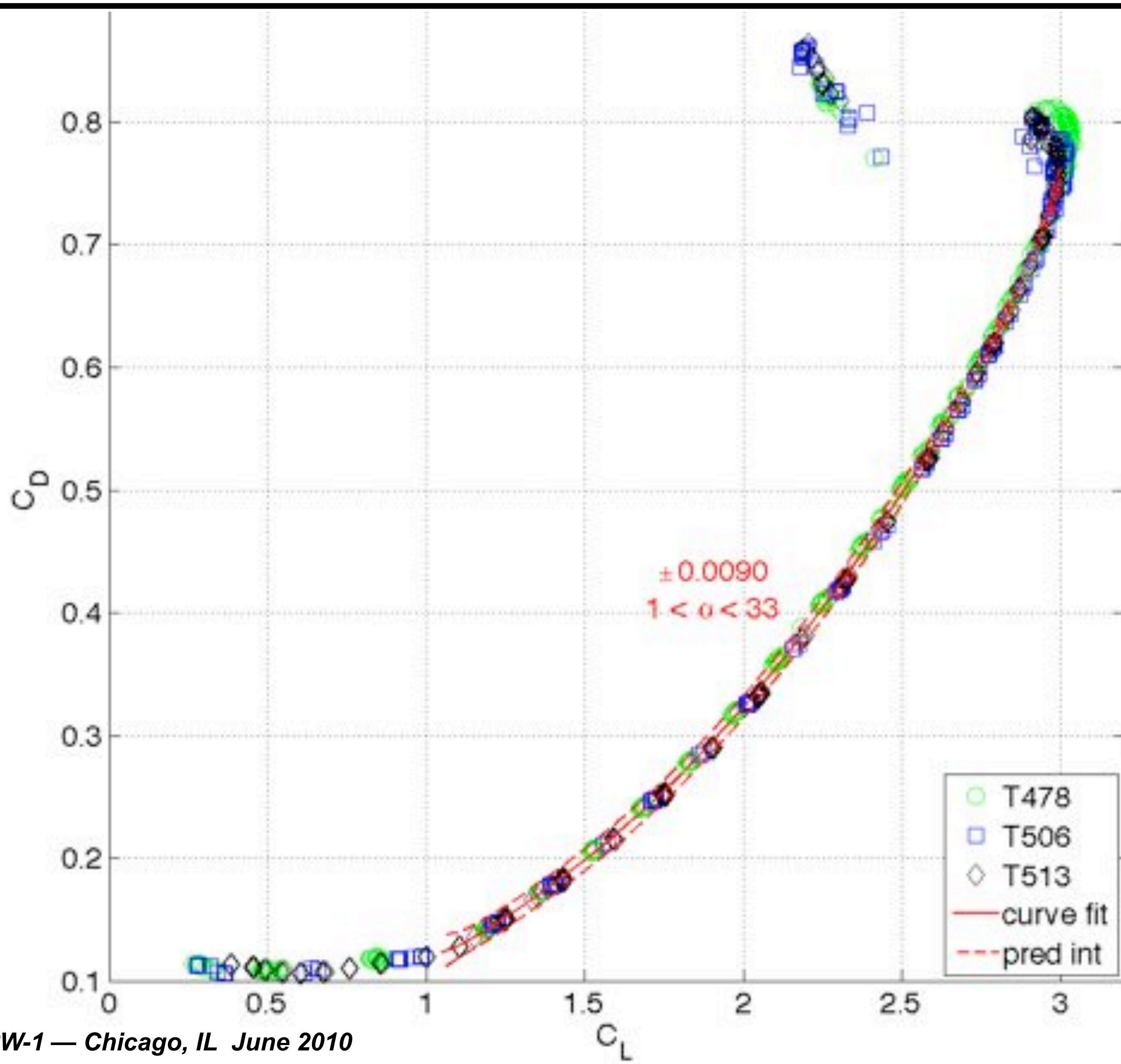

Conclusions about repeatability

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- Config 1 in 14x22
  - based on 3 tests from 1998, 2002, 2003
  - several known differences between tests
    - different balances
    - flap overlap rigging issues
    - different positions in the tunnel
    - one test had hot films on surface
    - some tunnel modifications between 1998 and 2002
  - prediction intervals are conservative
  - overall variations are about 2-3 times expected instrumentation uncertainty levels
  - variations within a given test are closer to expected instrumentation uncertainty levels
- Config 8 in 14x22
  - based on 3 back-to-back polars on one day in 1998
  - prediction intervals are well within expected instrumentation uncertainty

Summary

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- Provided an overview of testing done with this model
- Provided clarity to the config 1 flap overlap issues and to the body pod standoff
- Experimental Data
  - workshop is using config 1 and config 8 f/m and pressure data from the 14x22
  - Config 1 repeatability is rich with information
  - there is more data available on this model – some still requires more analysis

- Backup slides

14x22 Wall Corrections

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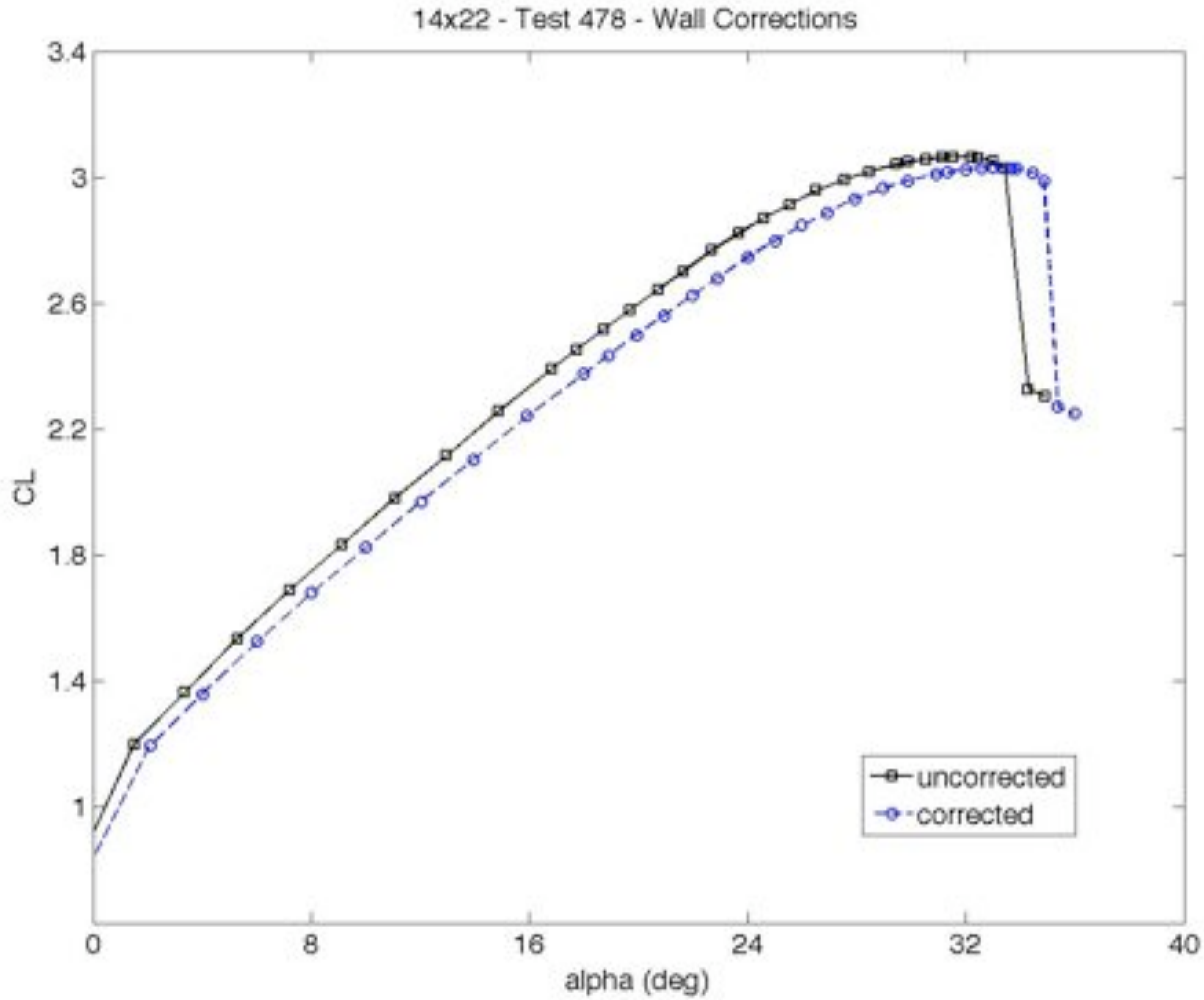

CL vs alpha – config 1 individual test residuals

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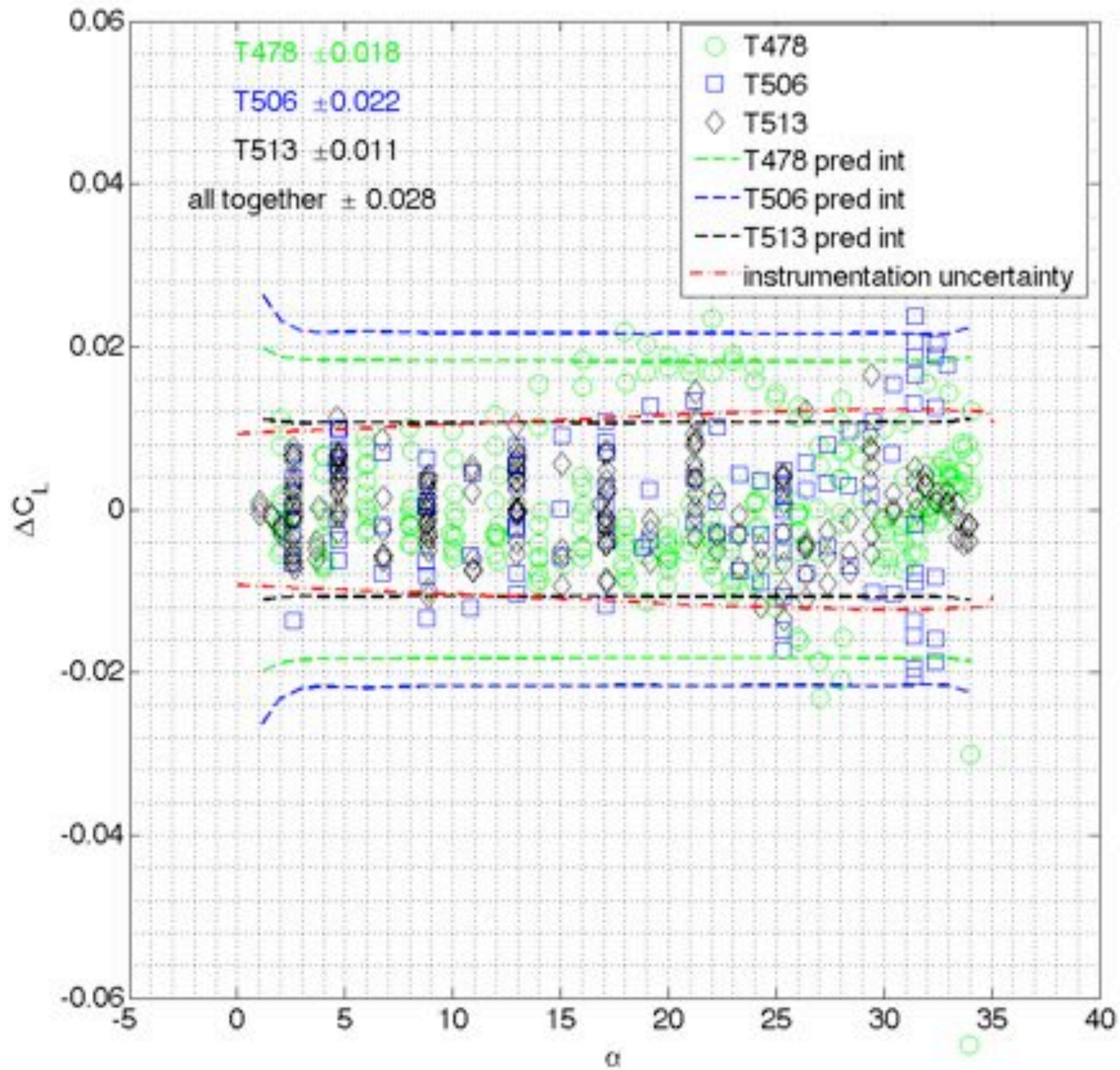
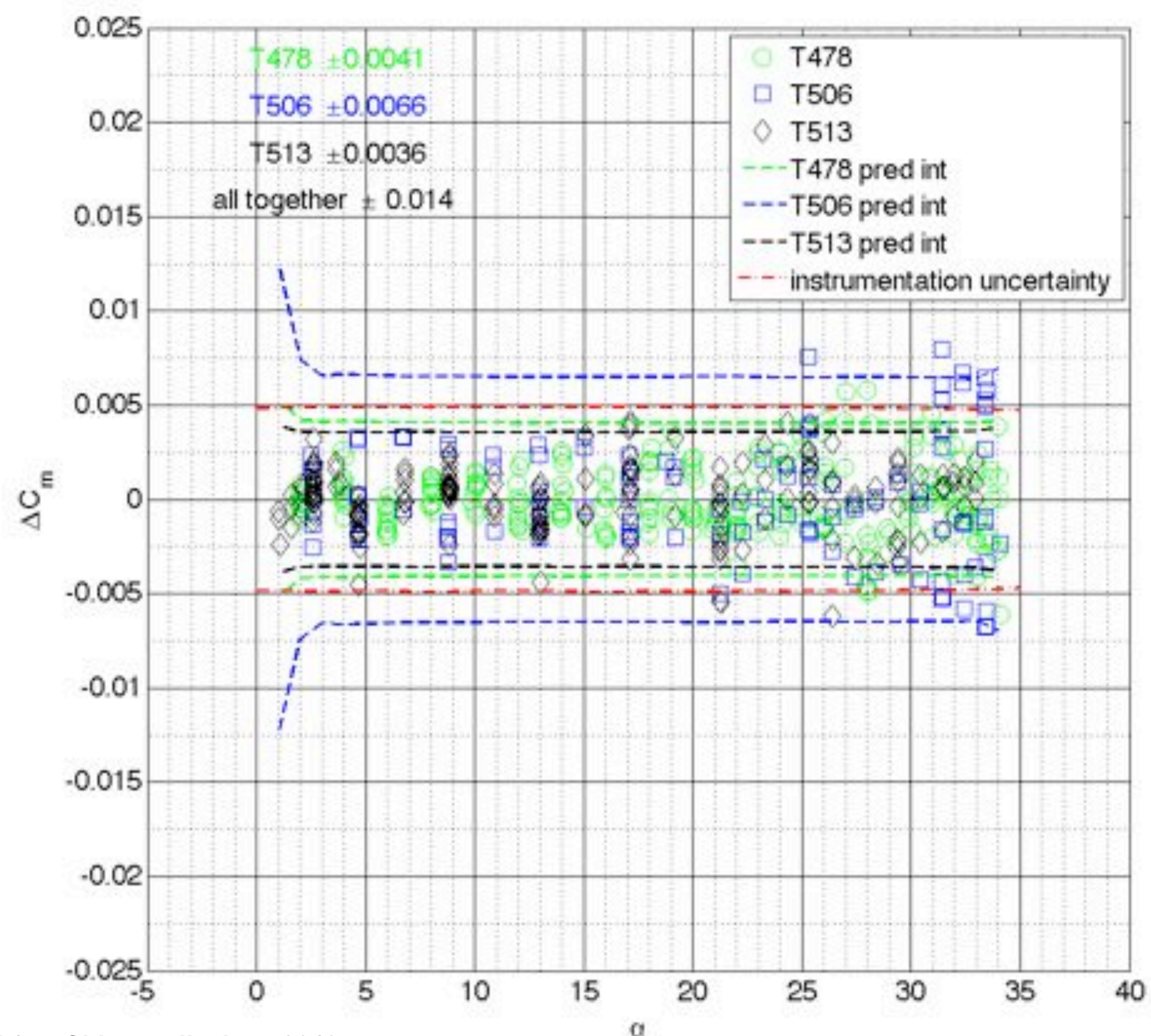
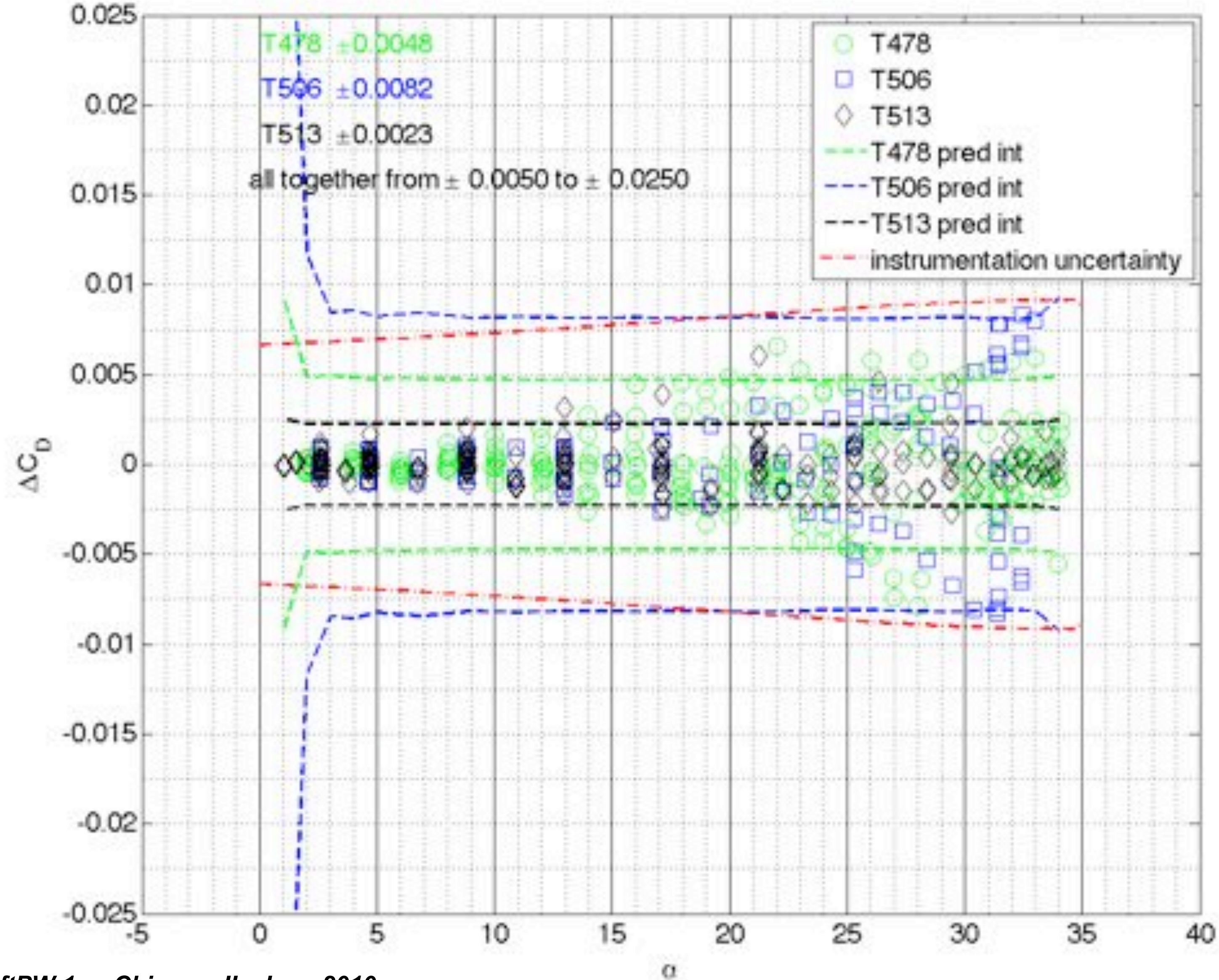


Cm vs alpha – config 1 individual test residuals

CFD High Lift Prediction Workshop



CD vs alpha – config 1 individual test residuals



CL vs alpha – config 8 residuals

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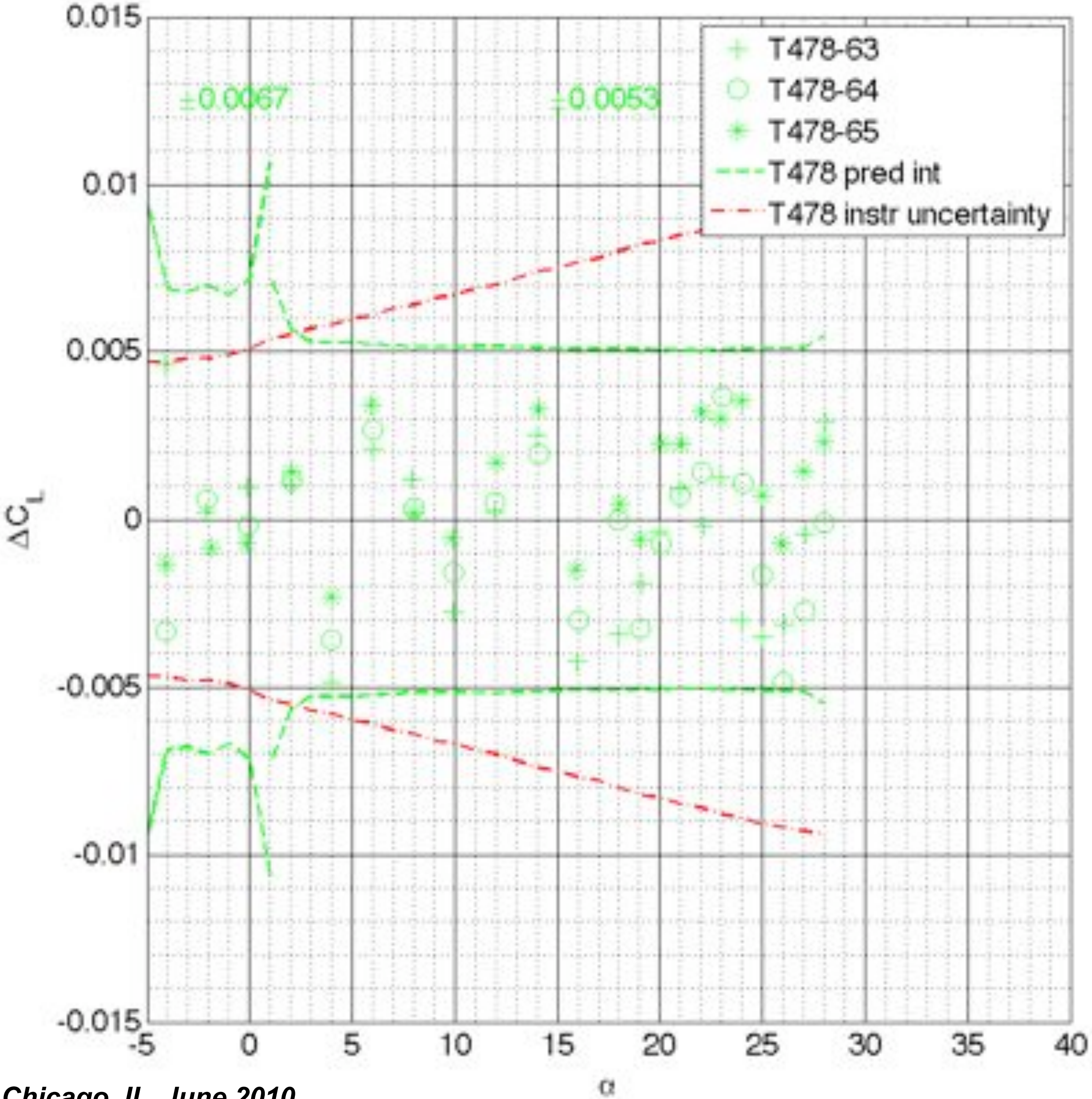
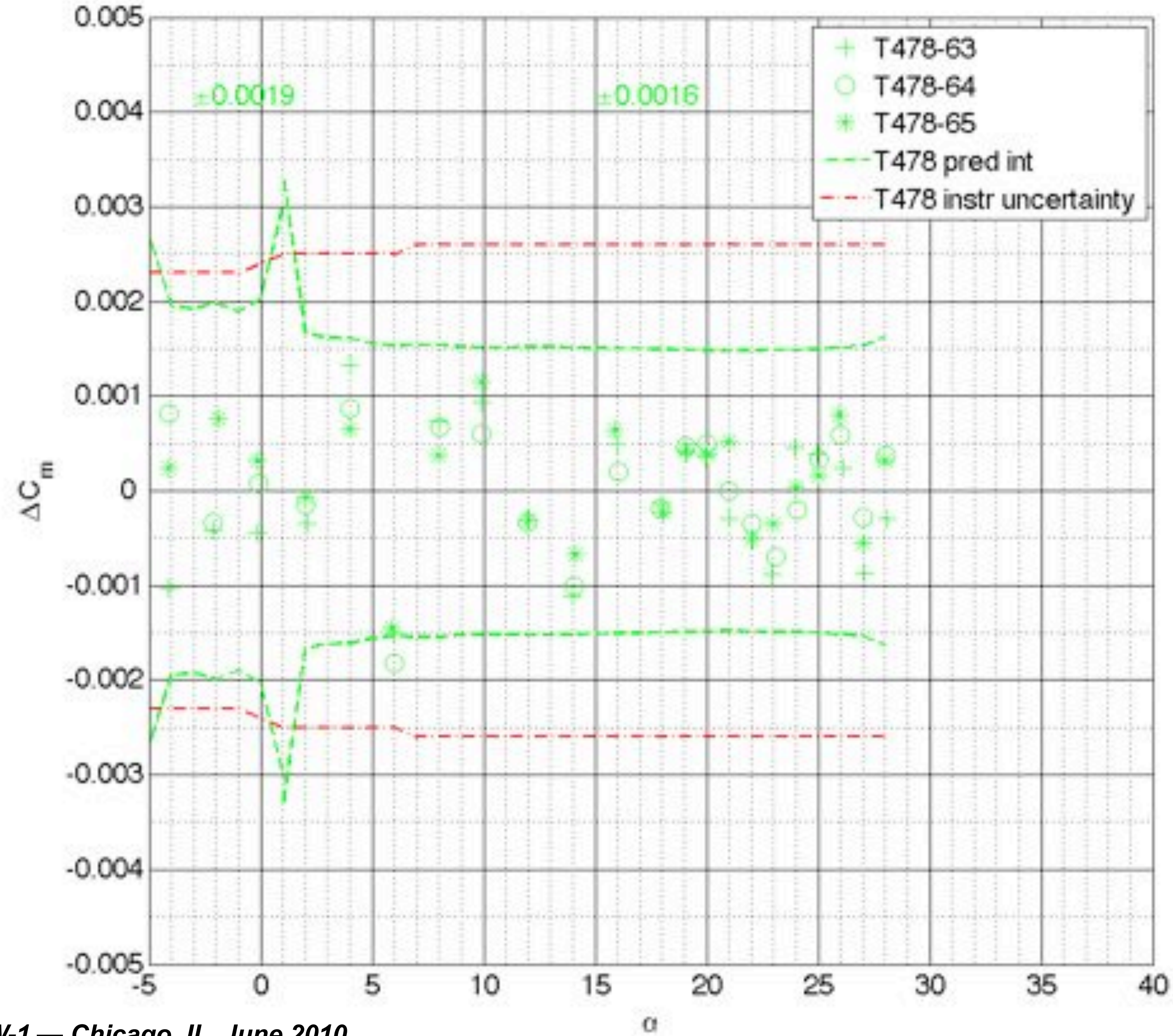


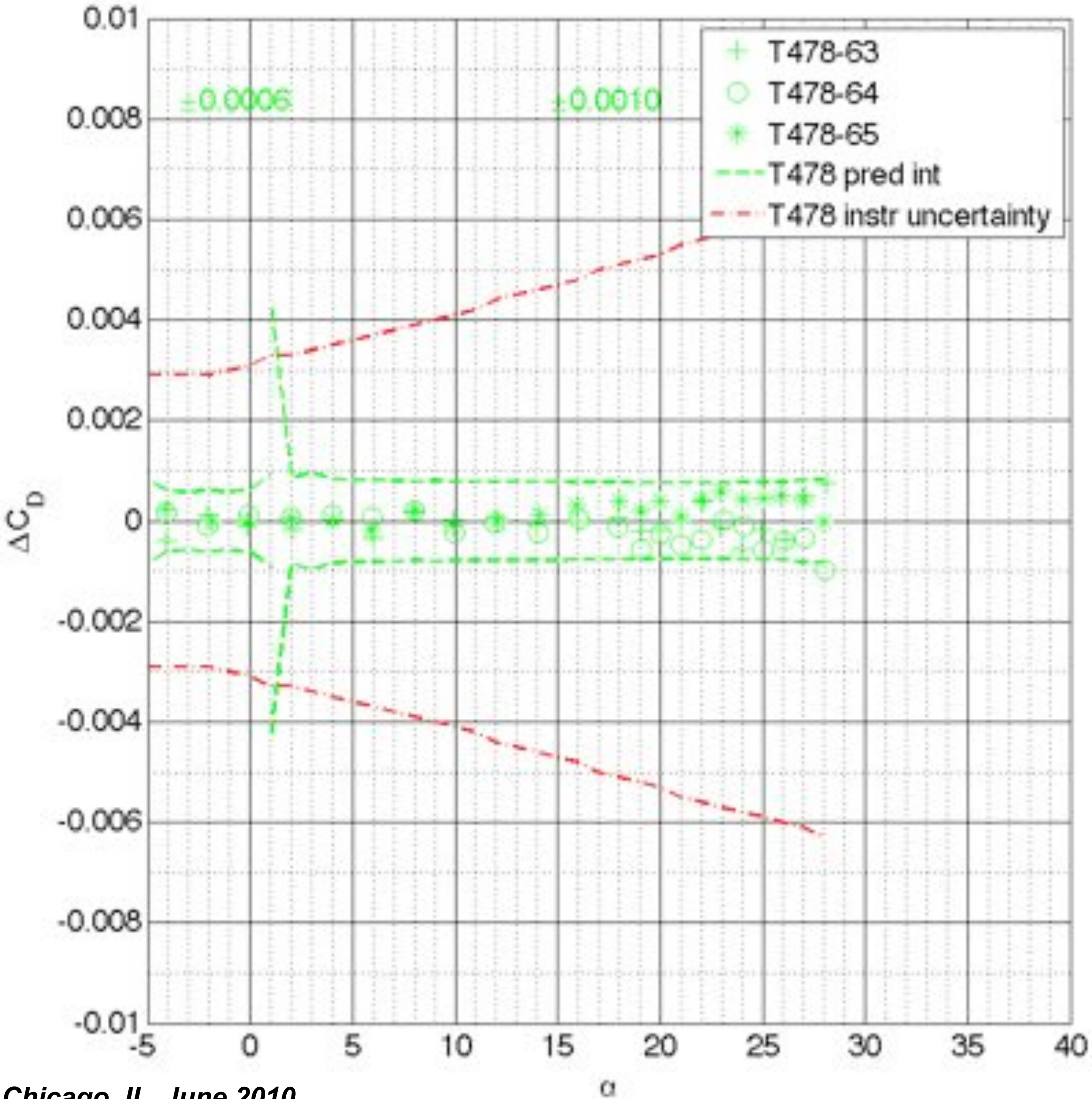
Cm vs alpha – config 8 residuals

CFD High Lift Prediction Workshop



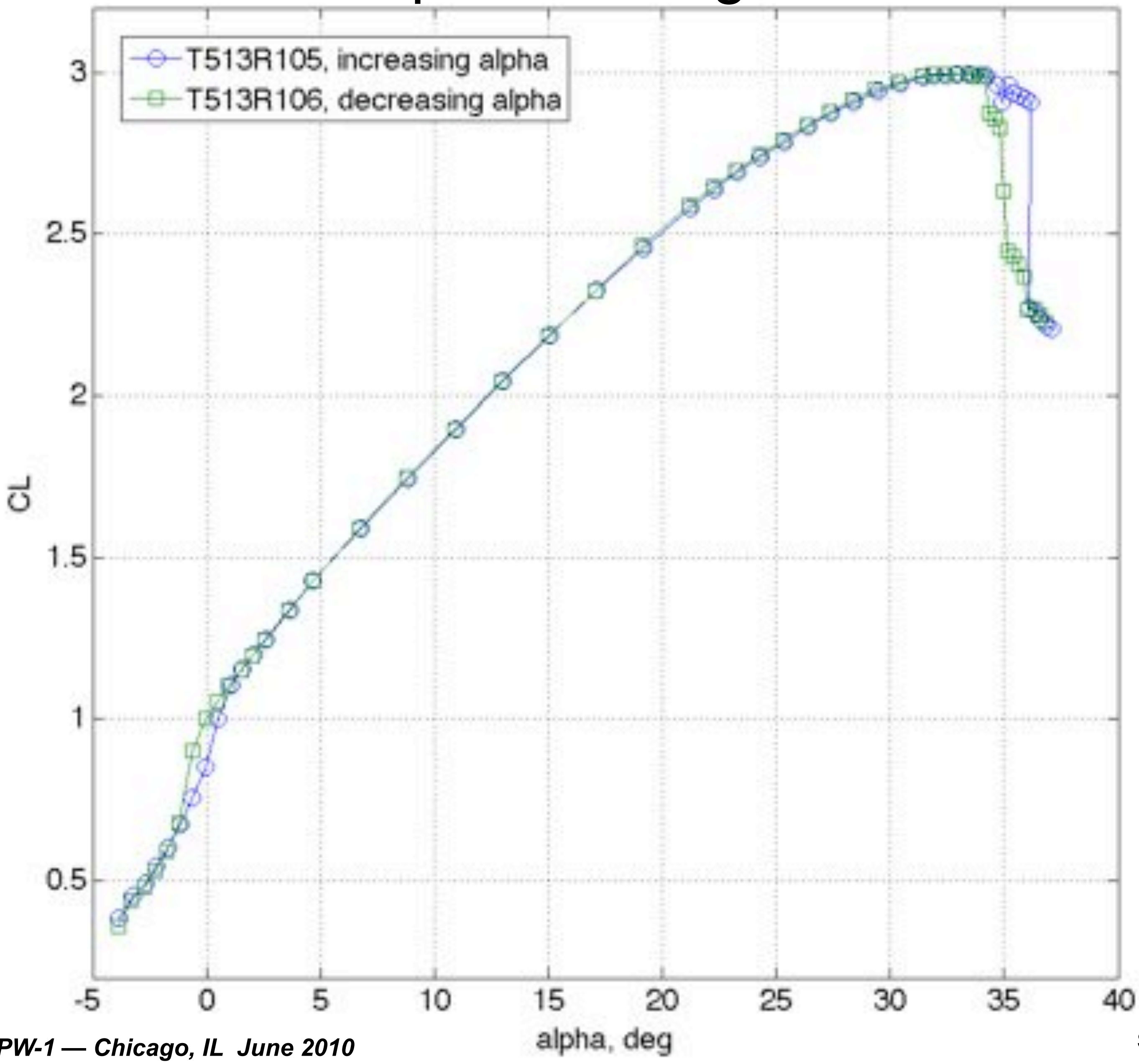
CD vs alpha – config 8 residuals

CFD High Lift Prediction Workshop



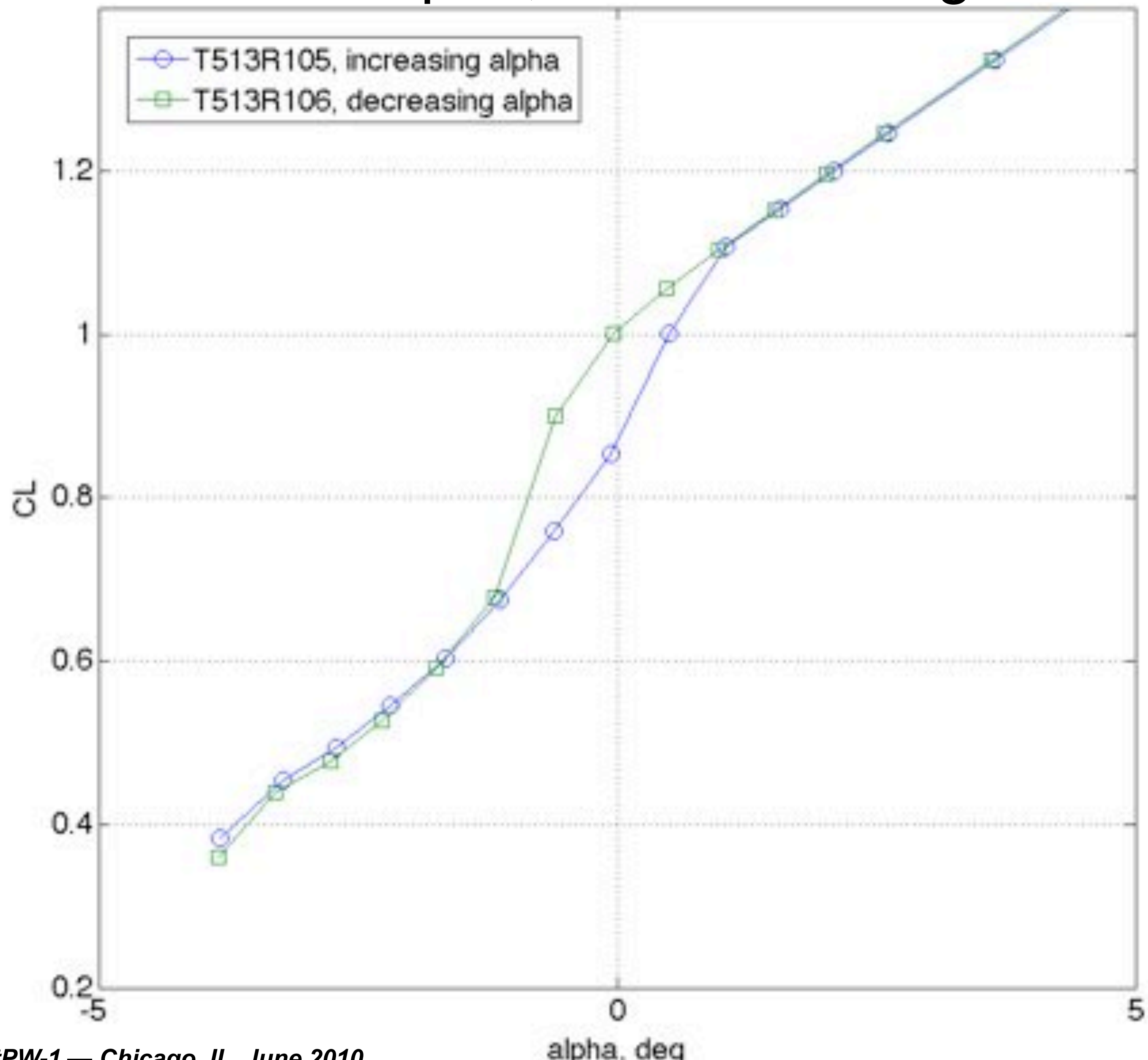
hysteresis – CL vs alpha – config 1

CFD High Lift Prediction



hysteresis – CL vs alpha, near 0 – config 1

CFD High Lift Prediction



hysteresis – CL vs alpha, CLmax – config 1

CFD High Lift Prediction